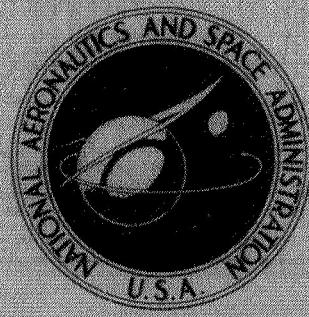


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ROLL-CONTROL EFFECTIVENESS OF SEVERAL
SPOILER CONFIGURATIONS ON AN AIRPLANE
MODEL WITH WING SWEET OF 55° AND 75°
AT SUPERSONIC MACH NUMBERS

by Clyde Hayes

Langley Research Center
Hampton, Va. 23365

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AND 75° AT SUPERSONIC MACH NUMBERS

By Clyde Hayes
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SUMMARY

An investigation has been conducted to determine the roll-control effectiveness of several spoiler configurations on an airplane model employing variable-sweep wings. The spoilers were located on either the movable outer wing panel or the fixed inboard panel. Leading-edge extensions, deflected to provide roll control, were also investigated. The outboard-spoiler tests were made at Mach numbers from 2.50 to 4.63 at a constant Reynolds number of 3.0×10^6 per 0.3048 meter (per foot). The inboard spoilers and leading-edge extensions were tested at Mach numbers from 1.50 to 2.86 at a constant Reynolds number of 2.0×10^6 per 0.3048 meter (per foot).

The results of the investigation showed that although the effectiveness of all the upper surface spoilers was small, there were configurations that produced rolling moments probably sufficient to trim the configuration and allow some maneuvering at low angles of attack. Lower wing-surface spoilers, inboard upper surface spoilers, and leading-edge extensions were all ineffective in producing significant amounts of rolling moment over the range of Mach number and angle of attack. Reversal of the direction of rolling moment with changing Mach number occurred with inboard spoilers.

INTRODUCTION

As part of a research program concerned with the aerodynamic characteristics of aircraft configurations having variable-sweep wings, an investigation has been performed in the Langley Unitary Plan wind tunnel to determine the roll-control effectiveness of various spoiler configurations. The problem of providing a suitable control surface for the wing is complicated by the large range of wing sweep angles encountered. A conventional control such as an aileron, designed to be effective at subsonic and low supersonic Mach numbers with a small sweep angle, would have a hinge line nearly aligned with the free-stream airflow at the high sweep angles appropriate for Mach numbers in the range from 3 to 4. Previous investigations of spoilers, such as the force tests reported in

references 1 to 3 and the pressure tests reported in references 4 to 7, although indicating that spoilers show promise as an effective roll-control device, were made at relatively low Mach numbers and do not consider the effects of higher Mach numbers and the high wing sweep angles usually employed.

The present investigation utilized a twin-jet fighter model having a variable-sweep wing with sweep angles up to 75° . Spoilers were installed on the top surface of the right wing and were intended to cause a positive rolling moment. The variables investigated included spoiler span and spanwise location and spoiler height and chordwise location over a range of Mach number from 2.50 to 4.63 at wing sweep angles of 55° and 75° . The effect of locating the spoiler on the lower surface of the wing was also investigated. Other configurations investigated were a spoiler located on the fixed inboard wing panel and leading-edge extensions, located near the wing tips of both wings and deflected to produce positive roll. Due to tunnel scheduling, the inboard spoilers and leading-edge extensions were investigated at a lower range of Mach number (1.50 to 2.86) than those for the rest of the tests.

The investigation was conducted at a range of angle of attack from approximately -4° to 28° with an angle of sideslip of 0° . The Reynolds number per 0.3048 meter (per foot) was maintained at 3.0×10^6 for Mach numbers from 2.50 to 4.63 for the outboard-spoiler tests and at 2.0×10^6 for Mach numbers from 1.50 to 2.86 for the leading-edge-extension tests and the inboard-spoiler tests.

SYMBOLS

All aerodynamic data except for those for lift and drag are presented in coefficient forms referred to the body-axis system. The lift and drag data are referred to the stability axis system. All coefficients are based on the geometry of the 75° swept wing. The moment center is on the fuselage reference line at a longitudinal location corresponding to the wing pivot point (fig. 1). Measurements and calculations were made in the U.S. Customary Units. They are presented in the text in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units.

b wing span, meters (feet)

b_r reference wing span, 0.462 meter (1.515 feet), measured at 75° sweep

c local wing chord, meters (feet)

\bar{c} reference mean geometric chord, 0.274 meter (0.9 foot)

| | |
|----------|--|
| C_D | drag coefficient, $\frac{\text{Drag}}{qS}$ |
| C_L | lift coefficient, $\frac{\text{Lift}}{qS}$ |
| C_l | rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb_r}$ |
| C_m | pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$ |
| C_n | yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb_r}$ |
| h | spoiler height, meters (feet) |
| M | Mach number |
| q | free-stream dynamic pressure, newtons/meter ² (pounds/foot ²) |
| S | reference wing area, 0.113 meter ² (1.212 foot ²) |
| x | chordwise location of spoiler measured from leading edge |
| α | angle of attack, referred to fuselage reference line, degrees |

MODEL

Details of the model are presented in figure 1. The model configuration selected for the investigation was a twin-jet fighter model having a variable-sweep wing. Details of the spoilers located on the upper surface of the movable portion of the model wing are presented in figure 1(b). Although the model coefficients are nondimensionalized in terms of the configuration with wings swept at 75°, the spoiler location and size are given in terms of the chord and semispan of the model with wings swept at 25°. The variables investigated included the spoiler span, spanwise location, spoiler height, and chordwise location, with the spoiler located either on the upper or lower surface of the wing. Spoilers were also tested on the inboard (fixed) portion of the wing (fig. 1(c)) as well as wing leading-edge extensions deflected to produce rolling moments (fig. 1(d)).

The model was mounted on an internal strain-gage balance which was attached to a rear-mounted sting. The sting, in turn, was attached to the tunnel central support system which allows remote control of the model attitude in the test section.

TESTS AND CORRECTIONS

The investigation was conducted in the Langley Unitary Plan wind tunnel. All tests except those of the leading-edge extensions were made in the high Mach number test section at Mach numbers of 2.50, 2.96, 3.96, and 4.63 at a constant Reynolds number of 3.0×10^6 per 0.3048 meter (per foot). Due to tunnel scheduling, the inboard spoilers and leading-edge extensions were investigated in the low Mach number test section at Mach numbers of 1.50, 1.90, 2.36, and 2.86 at a constant Reynolds number of 2.0×10^6 per 0.3048 meter (per foot). The free-stream stagnation temperature was maintained at 339° K (150° F) for Mach numbers from 1.50 to 2.96 and at 353° K (175° F) for Mach numbers of 3.96 and 4.63. The stagnation dewpoint was maintained at 239° K (-30° F) to avoid condensation effects. The angle of attack was varied from about -4° to 28° at 0° angle of sideslip. The results have been corrected for flow angularity and deflection of the balance and sting underload. No corrections were made for base and chamber pressures or internal flow.

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

| | Figure |
|---|--------|
| Effect of upper surface spoiler height with 55° swept wing. | |
| x/c = 0.65; span, 0.5b/2 | 2 |
| Effect of upper surface spoiler height with 75° swept wing. | |
| x/c = 0.65; span, 0.5b/2 | 3 |
| Effect of chordwise spoiler location with 55° swept wing. | |
| h/c = 0.09; span, 0.5b/2 | 4 |
| Effect of chordwise spoiler location with 75° swept wing. | |
| h/c = 0.09; span, 0.5b/2 | 5 |
| Effect of spoiler span and spanwise location with 55° swept wing. | |
| h/c = 0.09; x/c = 0.75 | 6 |
| Effect of spoiler span and spanwise location with 75° swept wing. | |
| h/c = 0.09; x/c = 0.75 | 7 |
| Effect of chordwise location of lower surface spoiler with 55° swept wing. | |
| h/c = 0.03; span, 0.5b/2 | 8 |
| Effect of chordwise location of lower surface spoiler with 75° swept wing. | |
| h/c = 0.03; span, 0.5b/2 | 9 |
| Effect of span and spanwise location of lower surface spoiler with 55° swept wing. h/c = 0.03; x/c = 0.75 | 10 |
| Effect of span and spanwise location of lower surface spoiler with 75° swept wing. h/c = 0.03; x/c = 0.75 | 11 |

Figure

| | |
|---|----|
| Effect of inboard spoiler with 75° swept wing | 12 |
| Effect of leading-edge extensions | 13 |

RESULTS AND DISCUSSION

Upper Surface Spoiler

The effects of upper surface spoiler height, chordwise location, span, and spanwise location on rolling moment and yawing moment are presented in figures 2 to 7. In general, these data indicate that the spoilers produced only small values of rolling moment for all configurations at low angles of attack, and these values decreased to zero as the angle of attack was increased. Increasing the wing sweep angle from 55° to 75° decreased the spoiler effectiveness by more than 50 percent. In all cases, favorable yawing moment was produced by spoiler deflection. The most effective upper surface spoiler configuration, having a wing sweep of 55°, 50 percent span, and $h/c = 0.09$ at $x/c = 0.65$ (fig. 2), produced a rolling moment of about 0.005 at $\alpha = 0^\circ$ with $M = 2.50$. Although this value of rolling moment is small, it is probably sufficient to trim the configuration and allow some maneuvering at low angles of attack.

Lower Surface Spoiler

The effect of locating the spoiler on the lower surface of the wing is shown in figures 8 to 11. The spoiler location on the lower surface of the right wing would, if effective, act as a flap and produce a negative rolling moment. Comparison of these data with the spoiler-off data of figures 2 and 3 shows that the lower surface spoilers were much less effective in producing rolling moment across the Mach number and angle-of-attack ranges than were the upper surface spoilers. Chordwise location, span, and spanwise location of the spoiler had little effect on the rolling or yawing-moment characteristics of the model at either wing sweep angles.

Inboard Spoilers

The effect of the inboard spoiler is shown in figure 12. With the spoiler in this location, only very small rolling moments were produced. The increments of C_l were about 0.001 and constant across the angle-of-attack range at Mach numbers greater than 1.90. At $M = 1.50$ and at low angles of attack at $M = 1.90$, the inboard spoiler produced rolling moments in an opposite direction from those at the higher Mach numbers and normally expected; that is, deflecting the right upper surface spoiler, which usually causes a roll to the right, caused a roll to the left. Also, yawing moments were produced that were at least as great and in most cases much greater than the rolling moments.

Because of the large yawing moments and the reversal of rolling moment at low Mach numbers, the inboard spoilers do not appear to be attractive as a roll control.

Leading-Edge Extensions

The leading-edge extensions as shown in figure 1(d) were tested over the Mach number range from 1.50 to 2.86 at a wing sweep angle of 75° . Data are presented in figure 13 for tests with the wing leading-edge extension on the left wing only and with leading-edge extensions on both wings. In both cases, the leading-edge extensions were deflected $22\frac{1}{2}^{\circ}$ in the direction expected to produce positive roll.

At 0° angle of attack, neither configuration had a significant effect on roll or yaw. With the leading-edge extension on the left wing only, a positive rolling moment was incurred as the angle of attack was increased. The rolling moment created was accompanied by essentially no effect on yaw. With both leading-edge extensions in place, essentially no effect on rolling moment was seen, although a small negative yawing moment was created as the angle of attack was increased.

CONCLUSIONS

An investigation has been conducted at Mach numbers from 2.50 to 4.63 to determine the effectiveness of several plane spoiler configurations on a twin-jet fighter model having a variable-sweep wing. The effectiveness of inboard spoilers and leading-edge extensions was also investigated at Mach numbers from 1.50 to 2.86. The following conclusions were obtained:

1. Although the effectiveness of all the upper surface spoilers was small, there were configurations that produced rolling moments probably sufficient to trim the configuration and allow some maneuvering at low angles of attack.
2. Lower wing-surface spoilers, inboard upper surface spoilers, and leading-edge extensions were all ineffective in producing significant amounts of rolling moment over the range of Mach number and angle of attack.
3. Reversal of the direction of rolling moment with changing Mach number occurred with inboard spoilers.

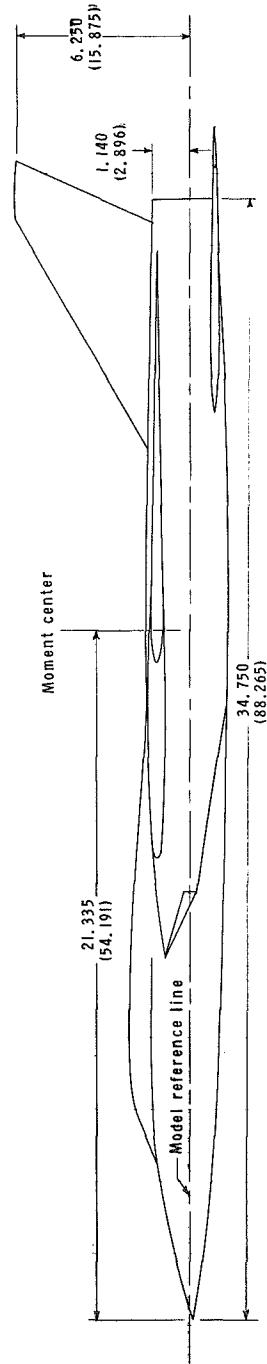
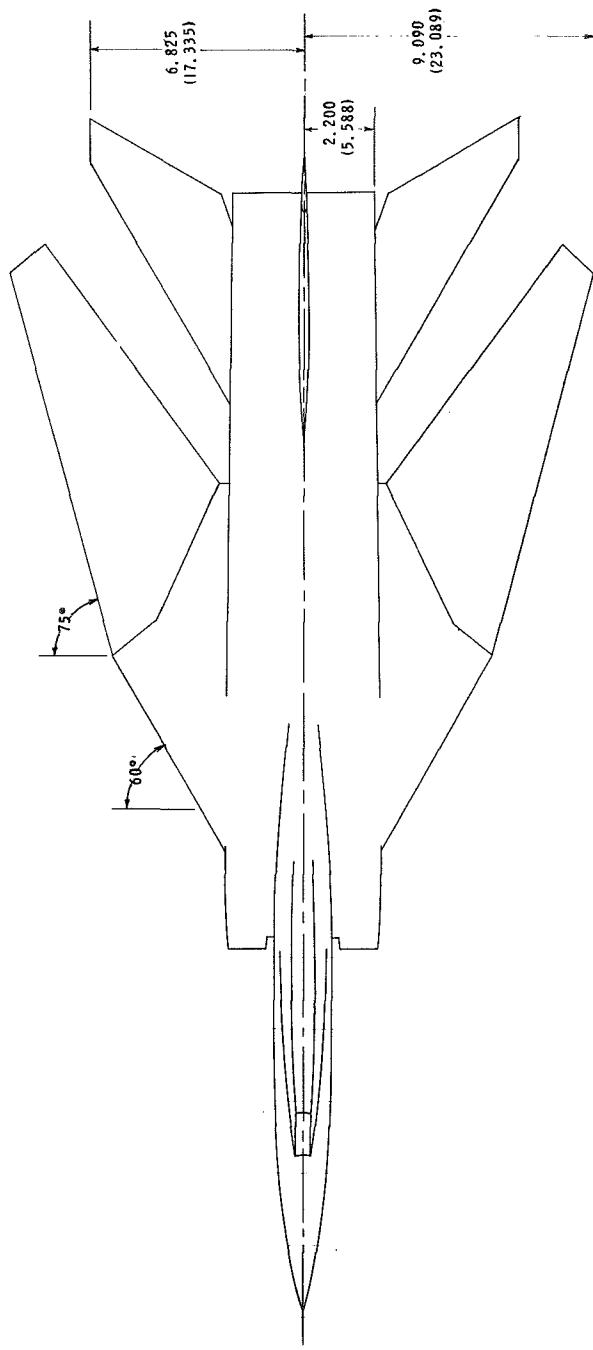
Langley Research Center,

National Aeronautics and Space Administration,

Hampton, Va., February 12, 1971.

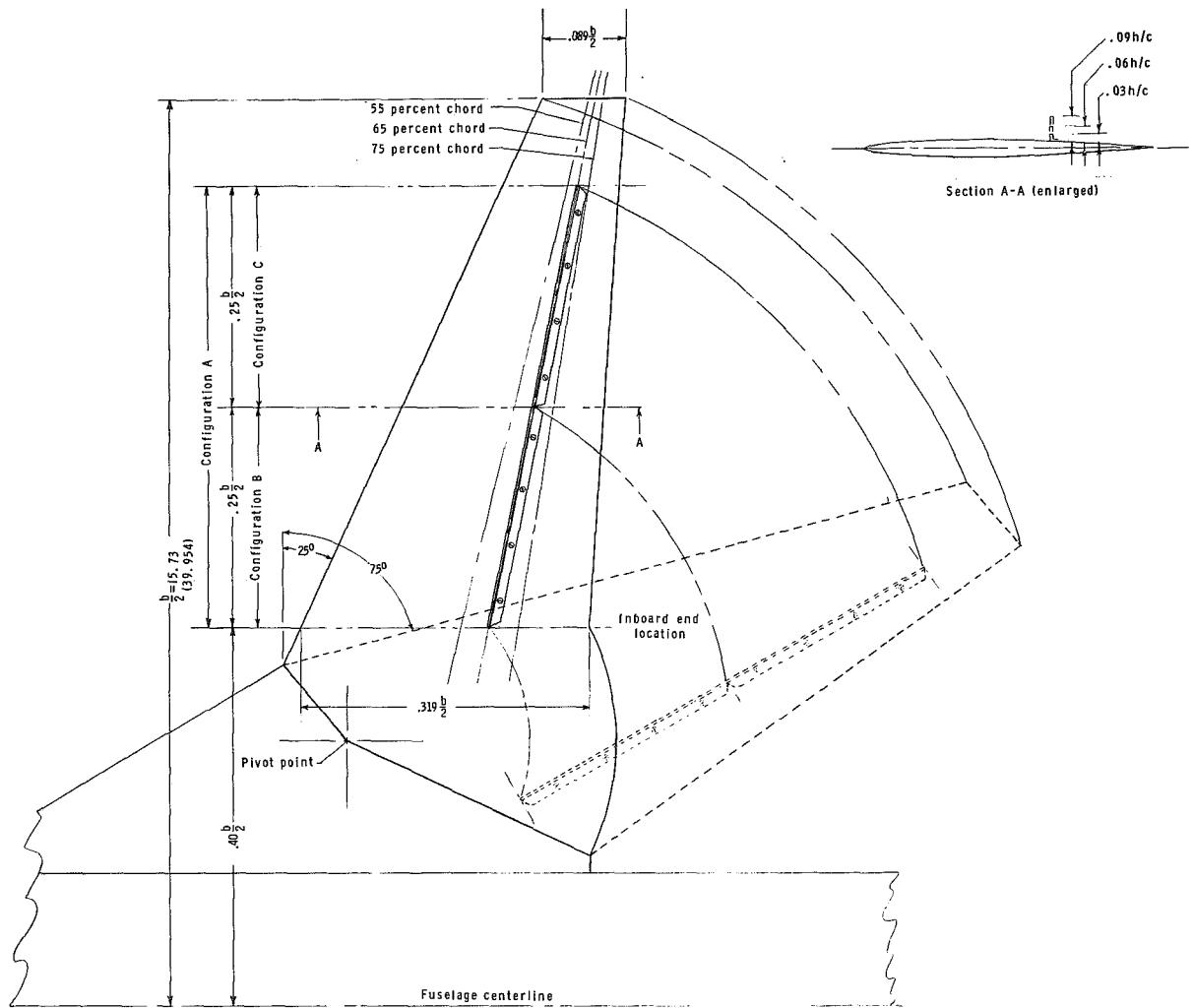
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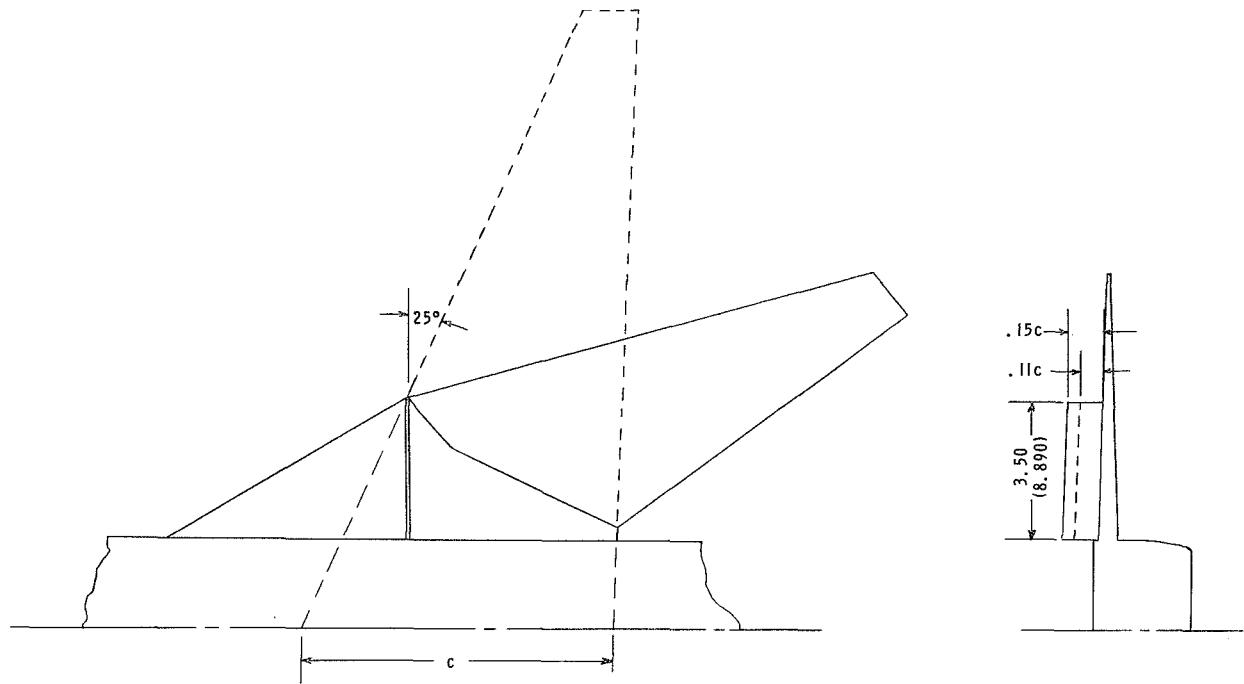
(a) General arrangement of the complete model.

Figure 1.- Details of the model. All dimensions are given in inches (centimeters) unless otherwise specified.

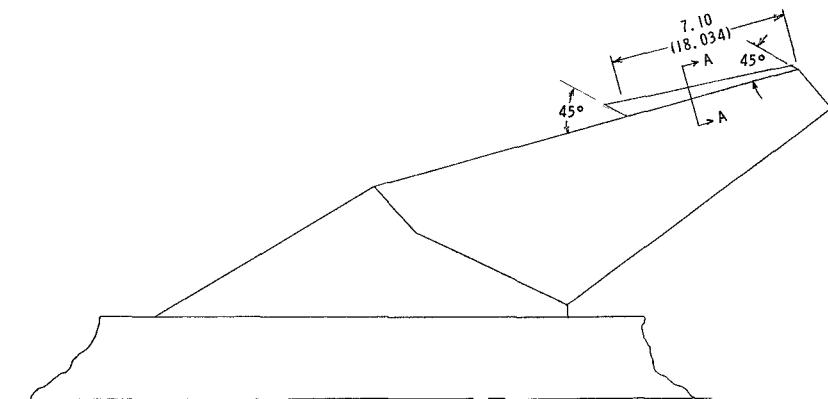
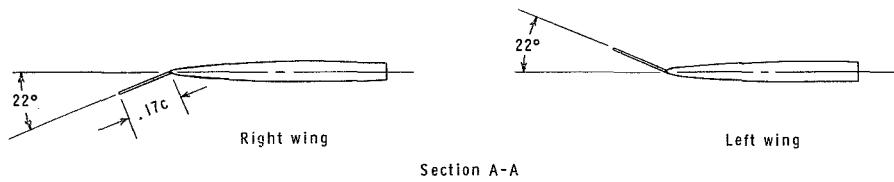


(b) Outboard spoiler.

Figure 1.- Continued.



(c) Inboard spoiler.



(d) Leading-edge extensions.

Figure 1.- Concluded.

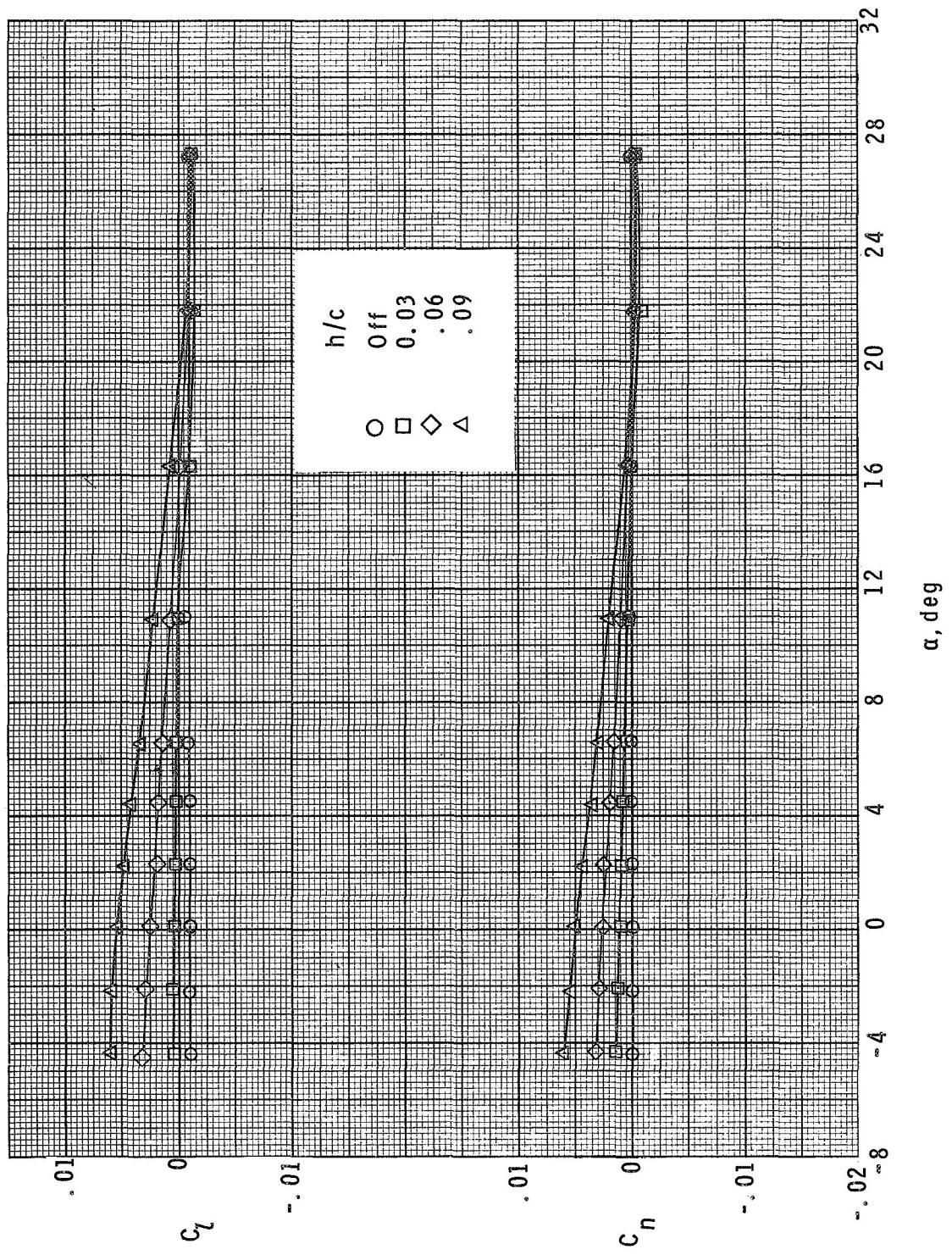
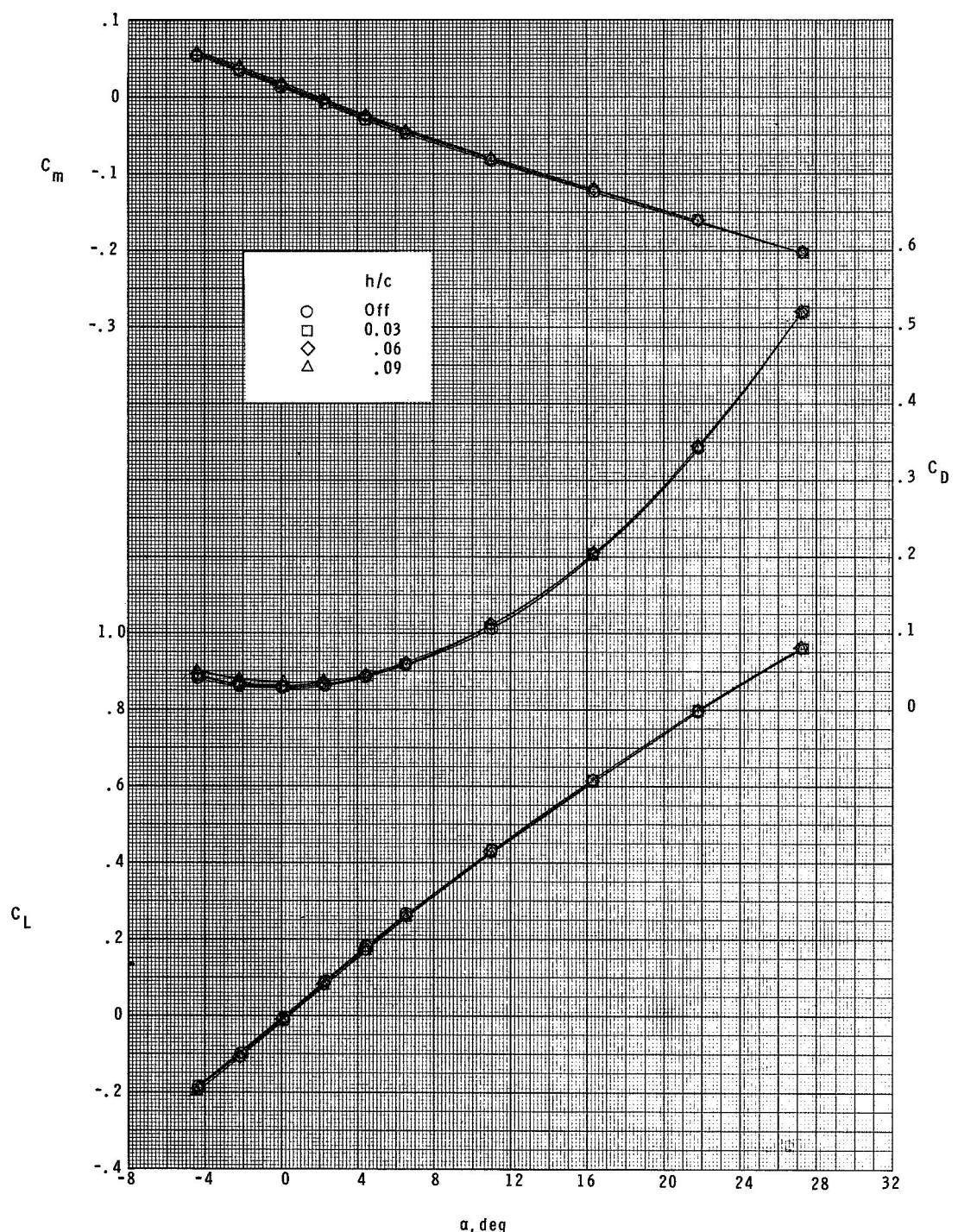
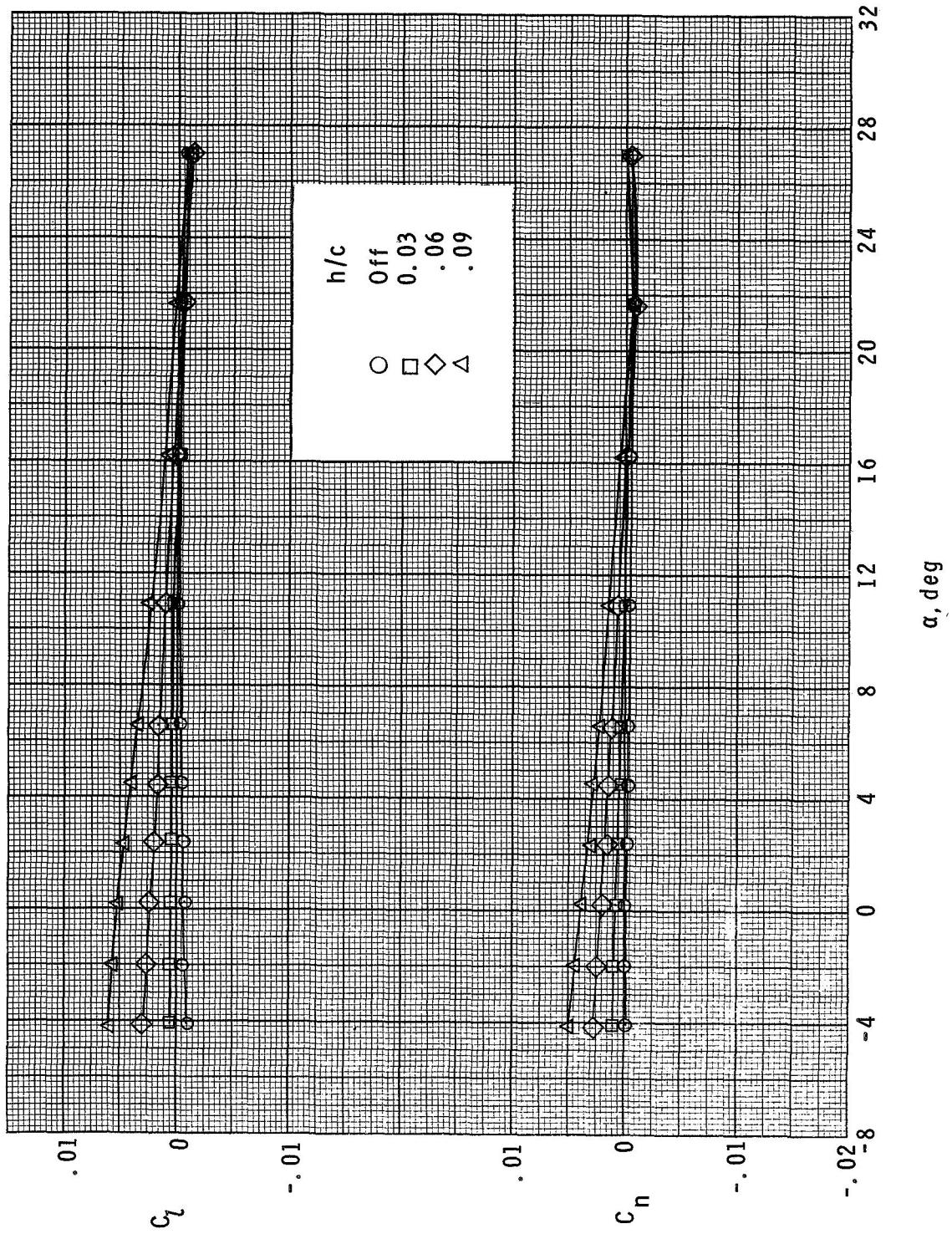


Figure 2.- Effect of upper surface spoiler height with 55° swept wing. $x/c = 0.65$; span, 0.5b/2.
 (a) $M = 2.50$.



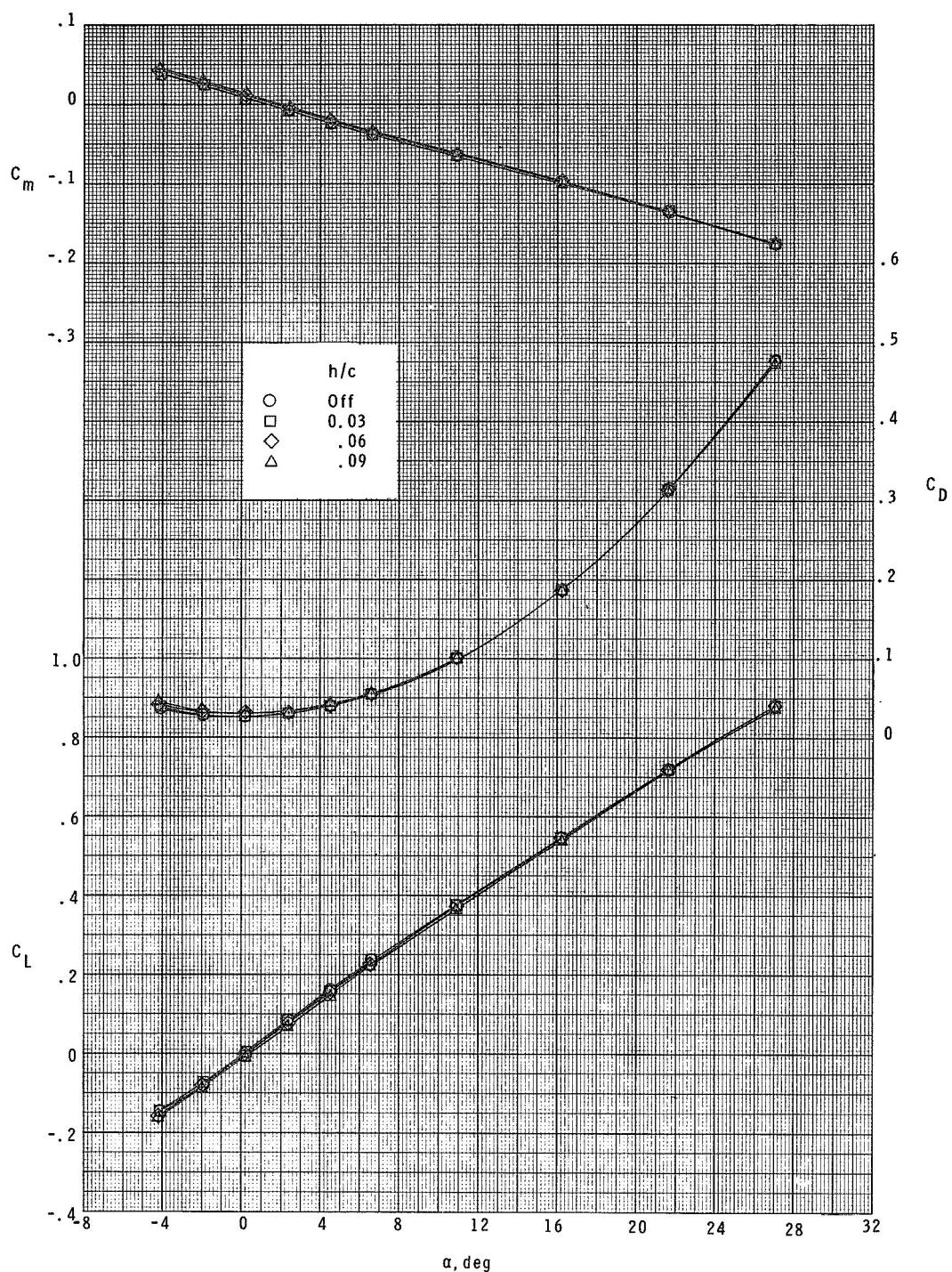
(a) $M = 2.50$. Concluded.

Figure 2.- Continued.



(b) $M = 2.96$.

Figure 2.- Continued.



(b) $M = 2.96$. Concluded.

Figure 2.- Continued.

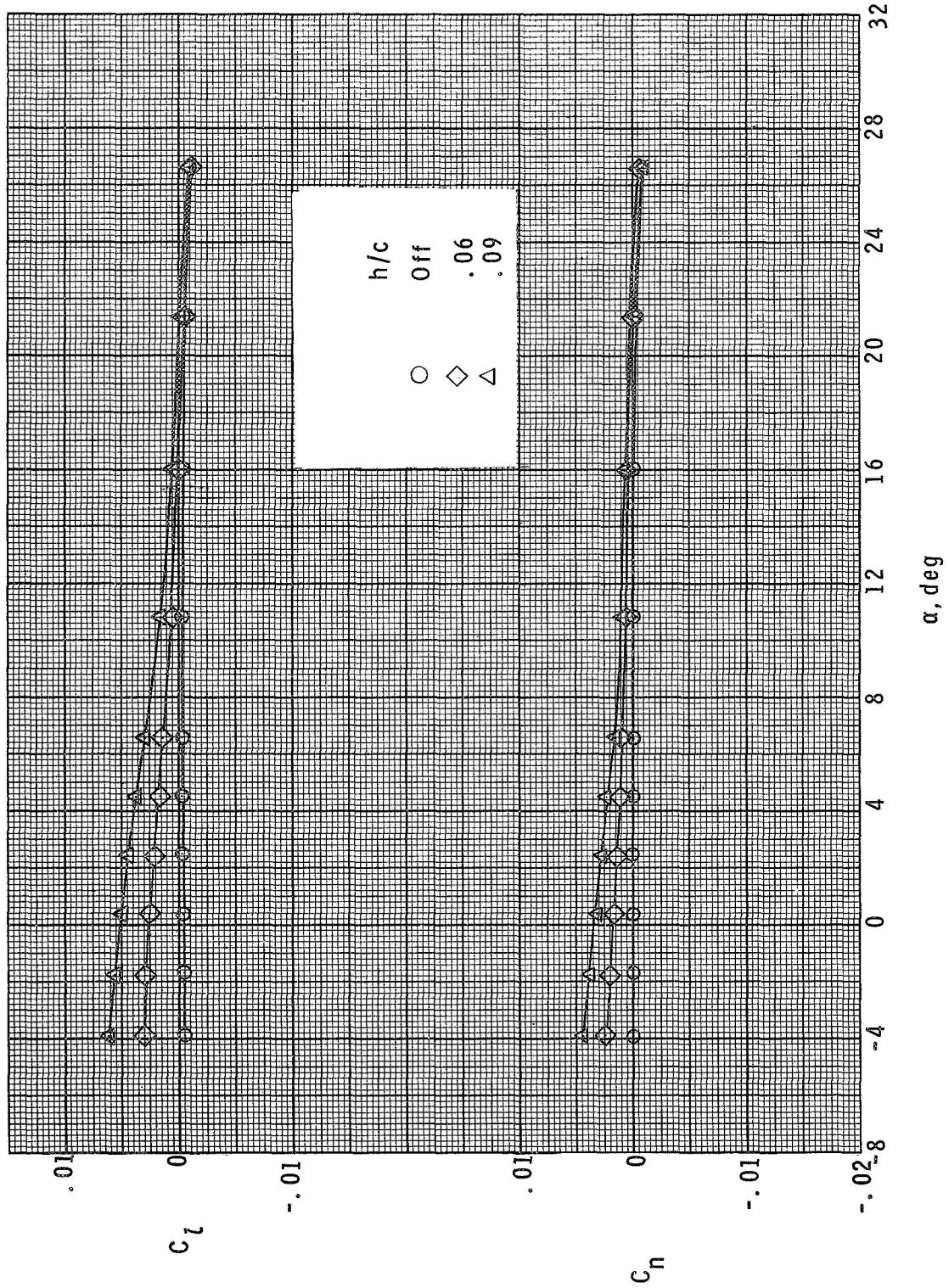
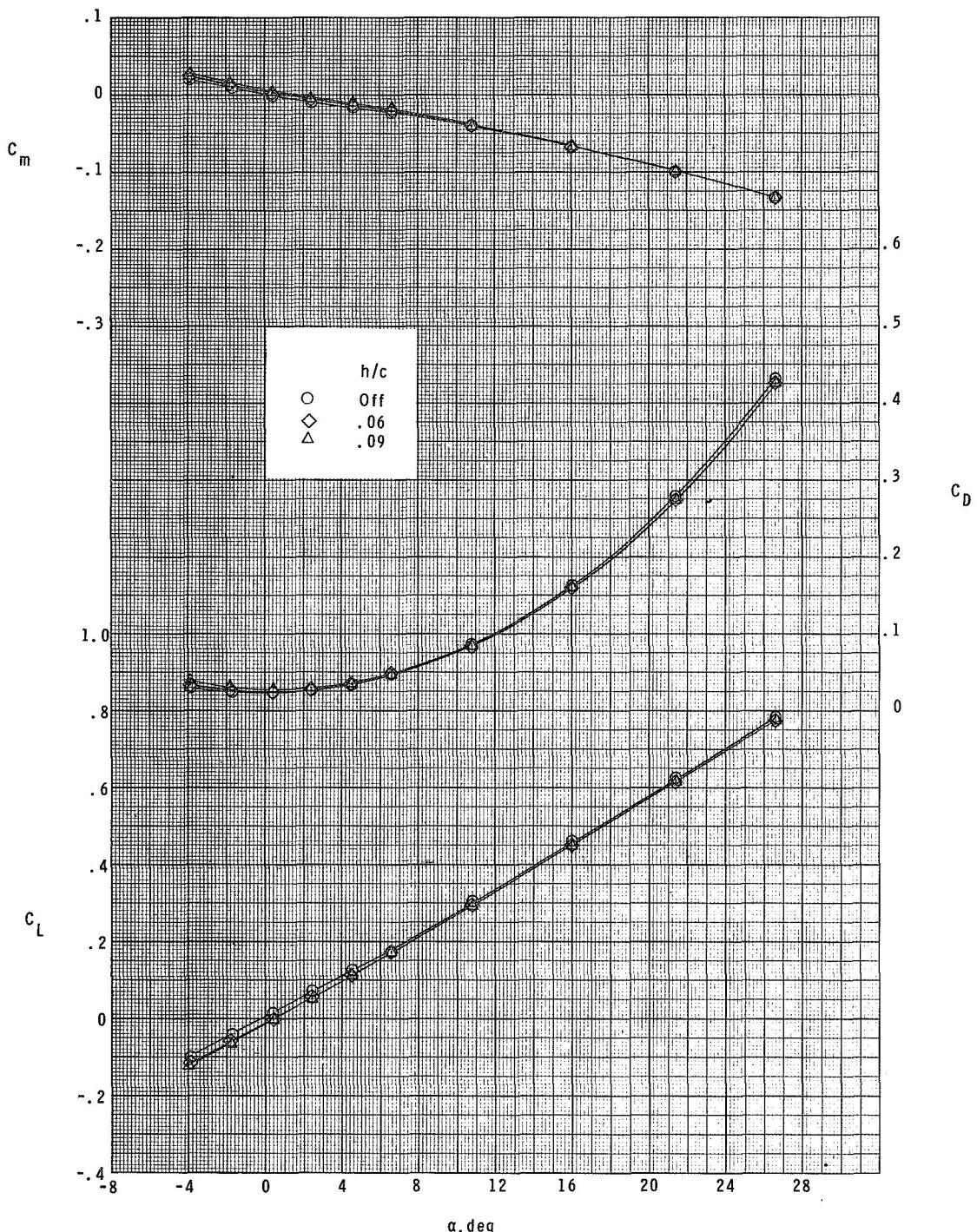
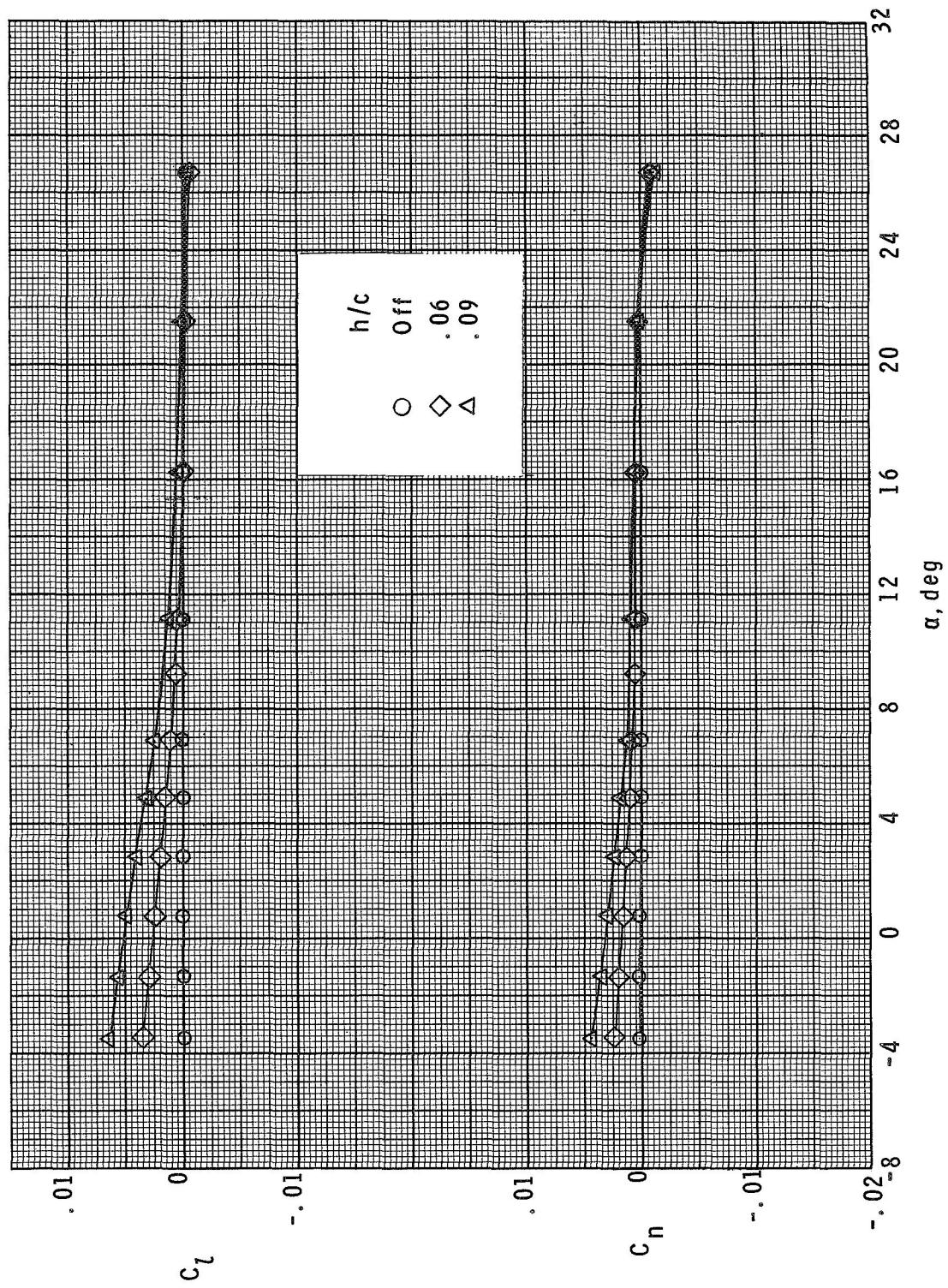


Figure 2. -- Continued.



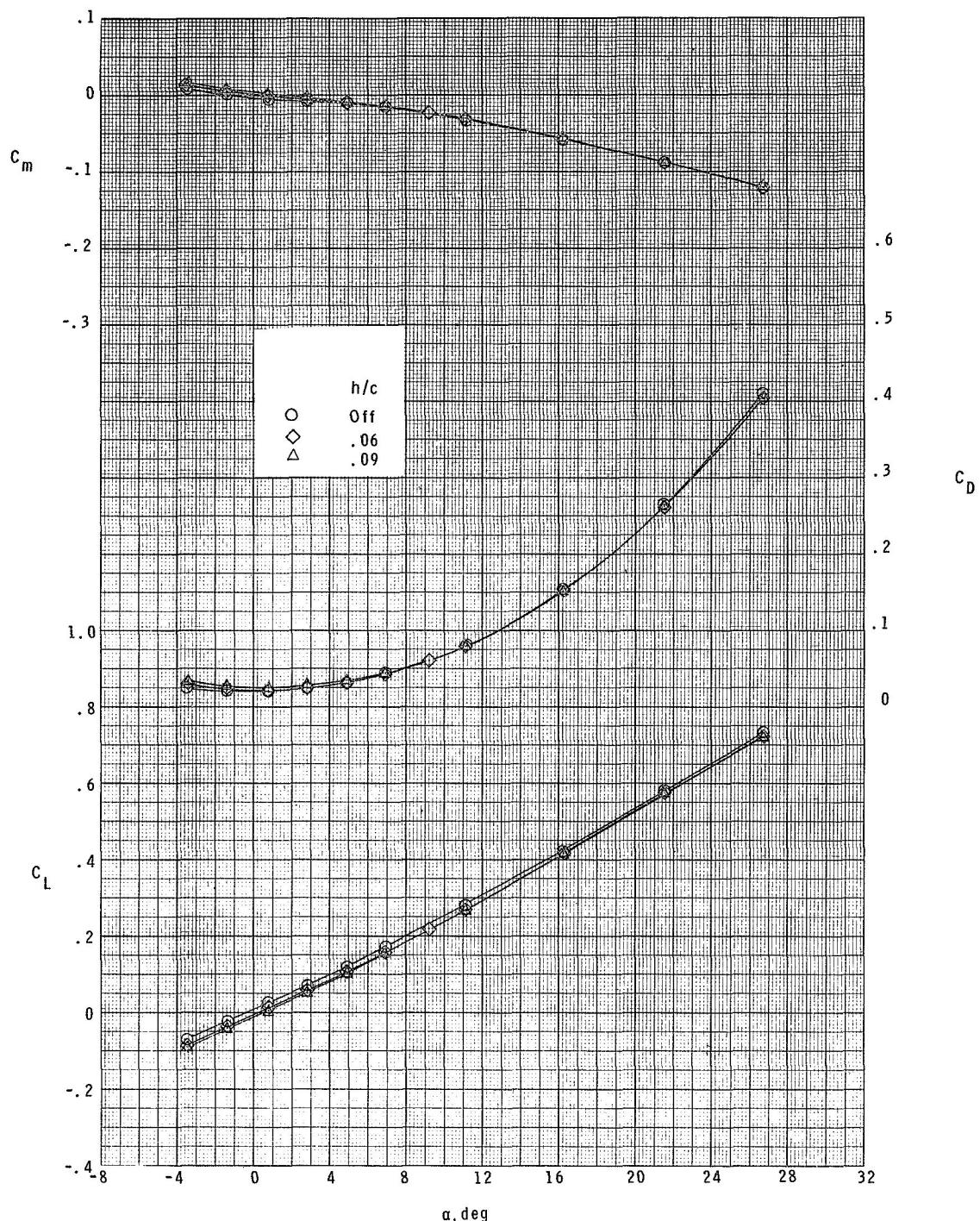
(c) $M = 3.96$. Concluded.

Figure 2.- Continued.



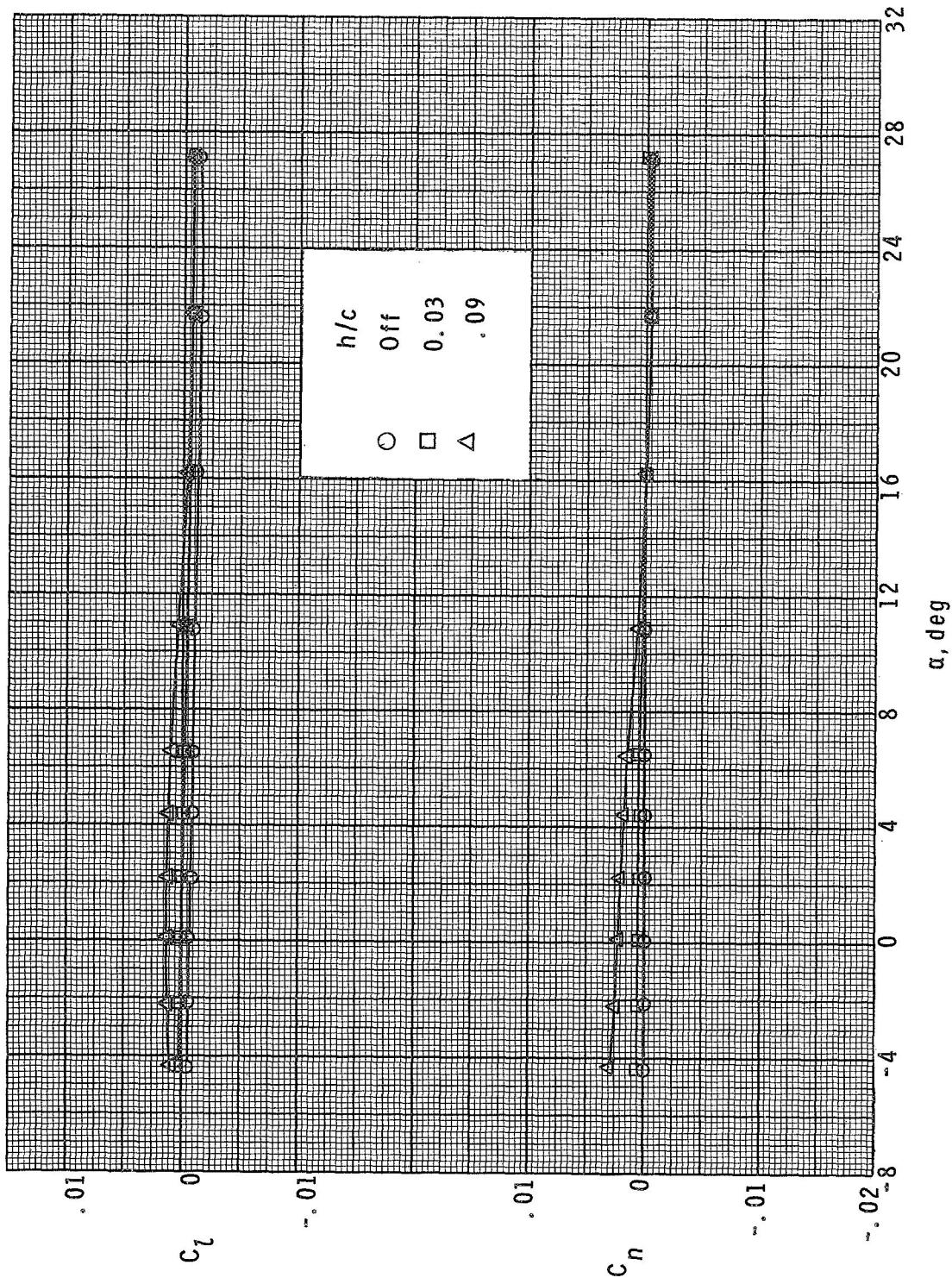
(d) $M = 4.63$.

Figure 2. - Continued.



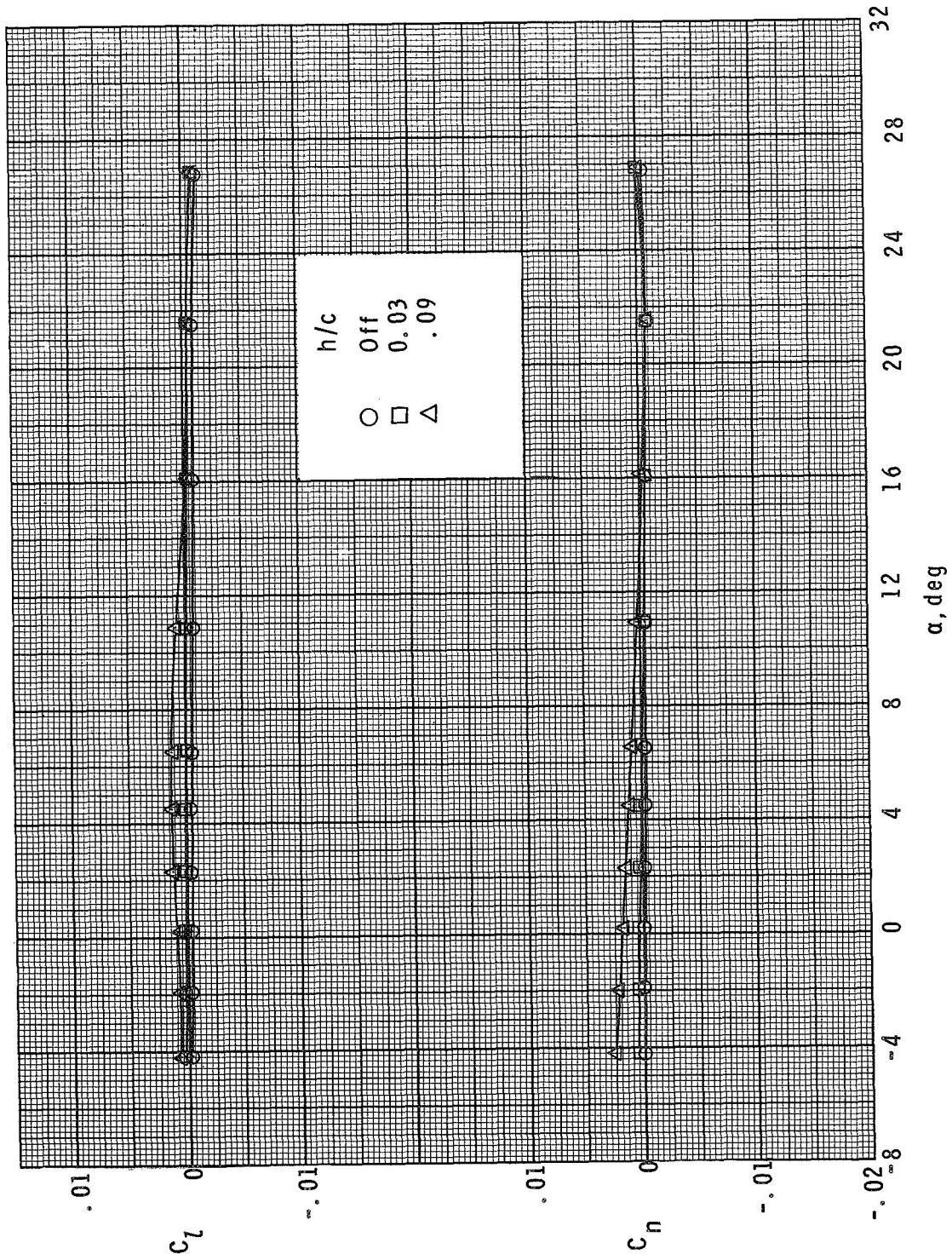
(d) $M = 4.63$. Concluded.

Figure 2.- Concluded.



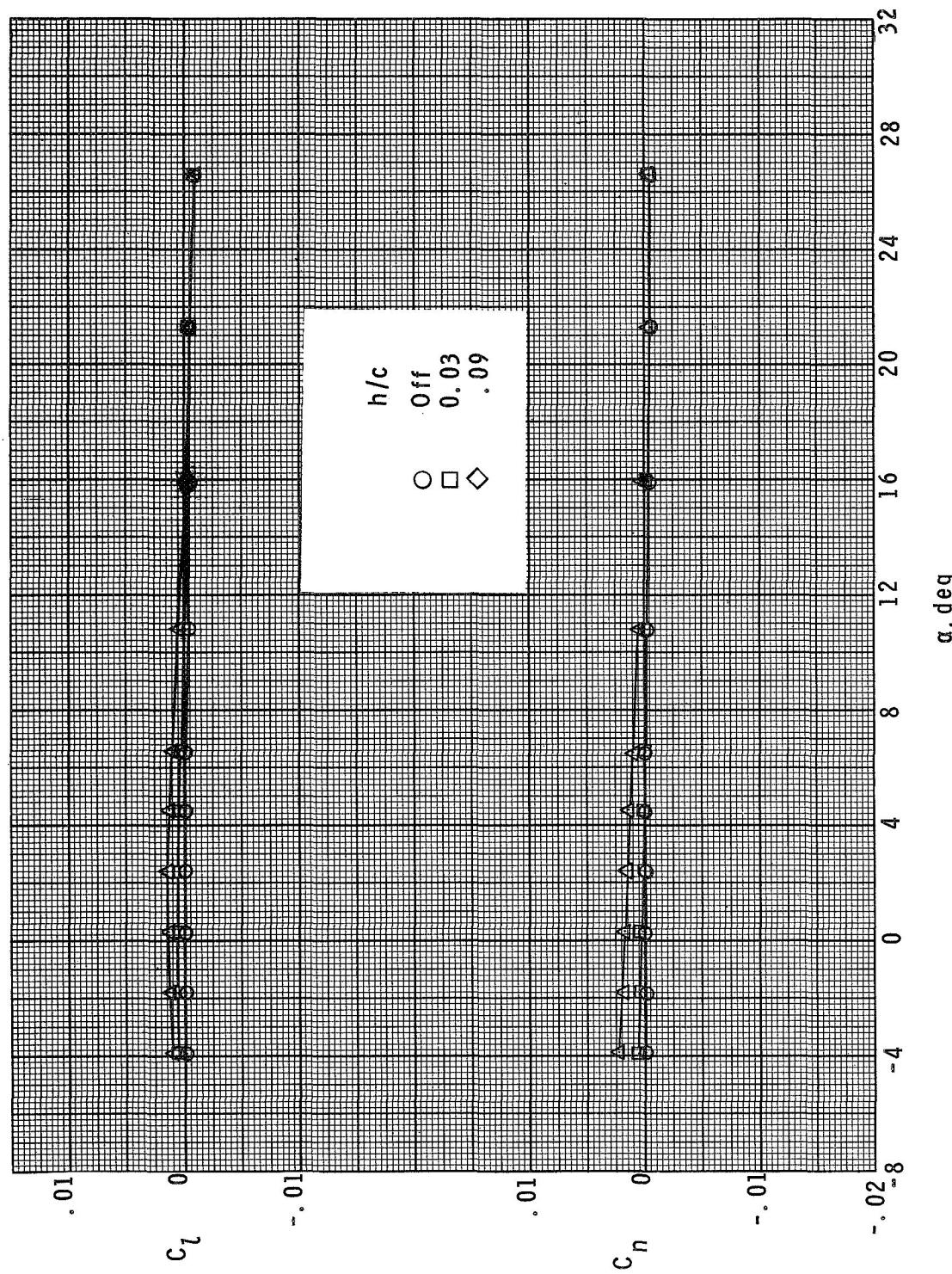
(a) $M = 2.50$.

Figure 3.- Effect of upper surface spoiler height with 75° swept wing. $x/c = 0.65$; span, 0.5b/2.



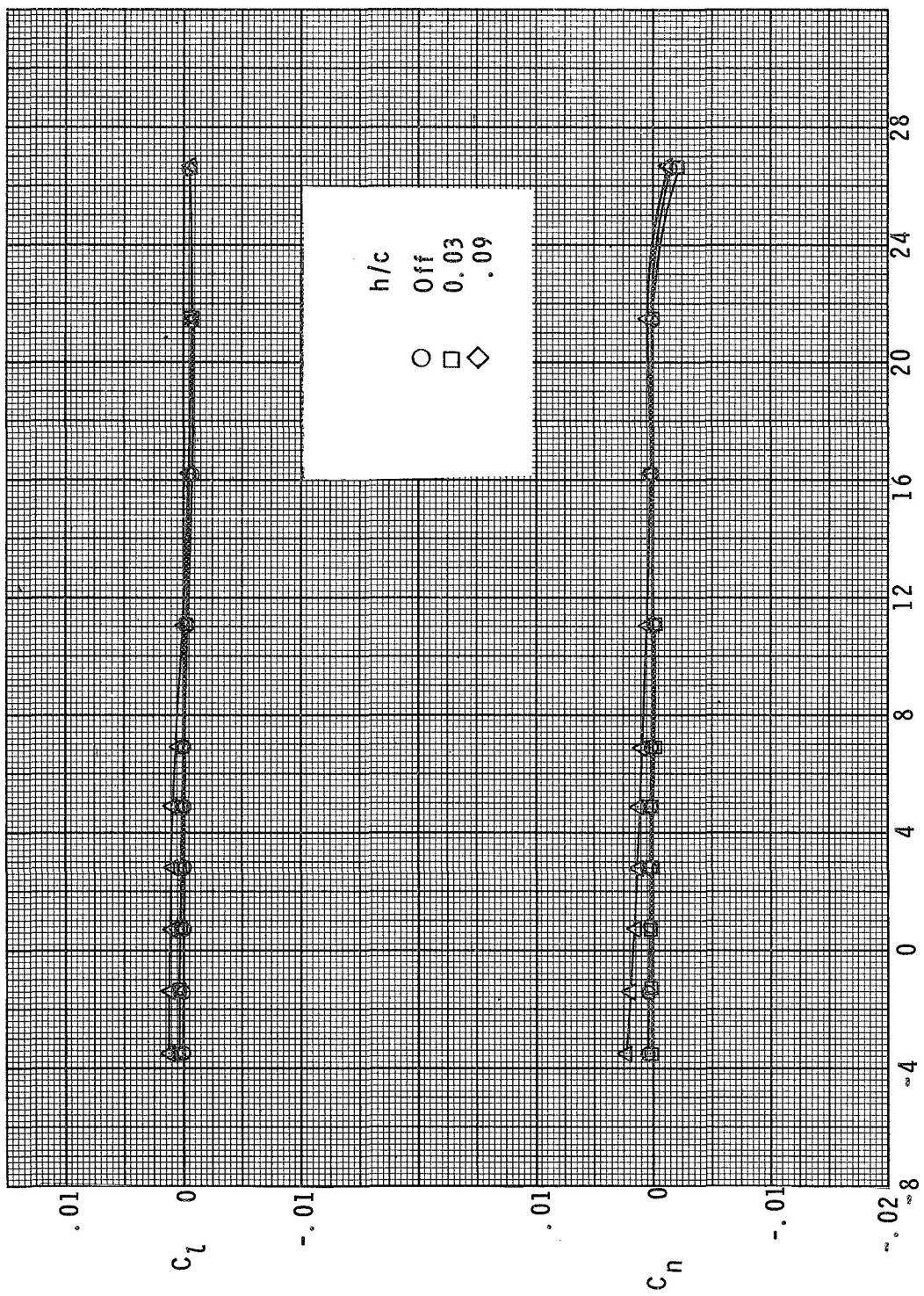
(b) $M = 2.96$.

Figure 3.- Continued.



(c) $M = 3.96$.

Figure 3.- Continued.



(d) $M = 4.63$.

Figure 3.— Concluded.

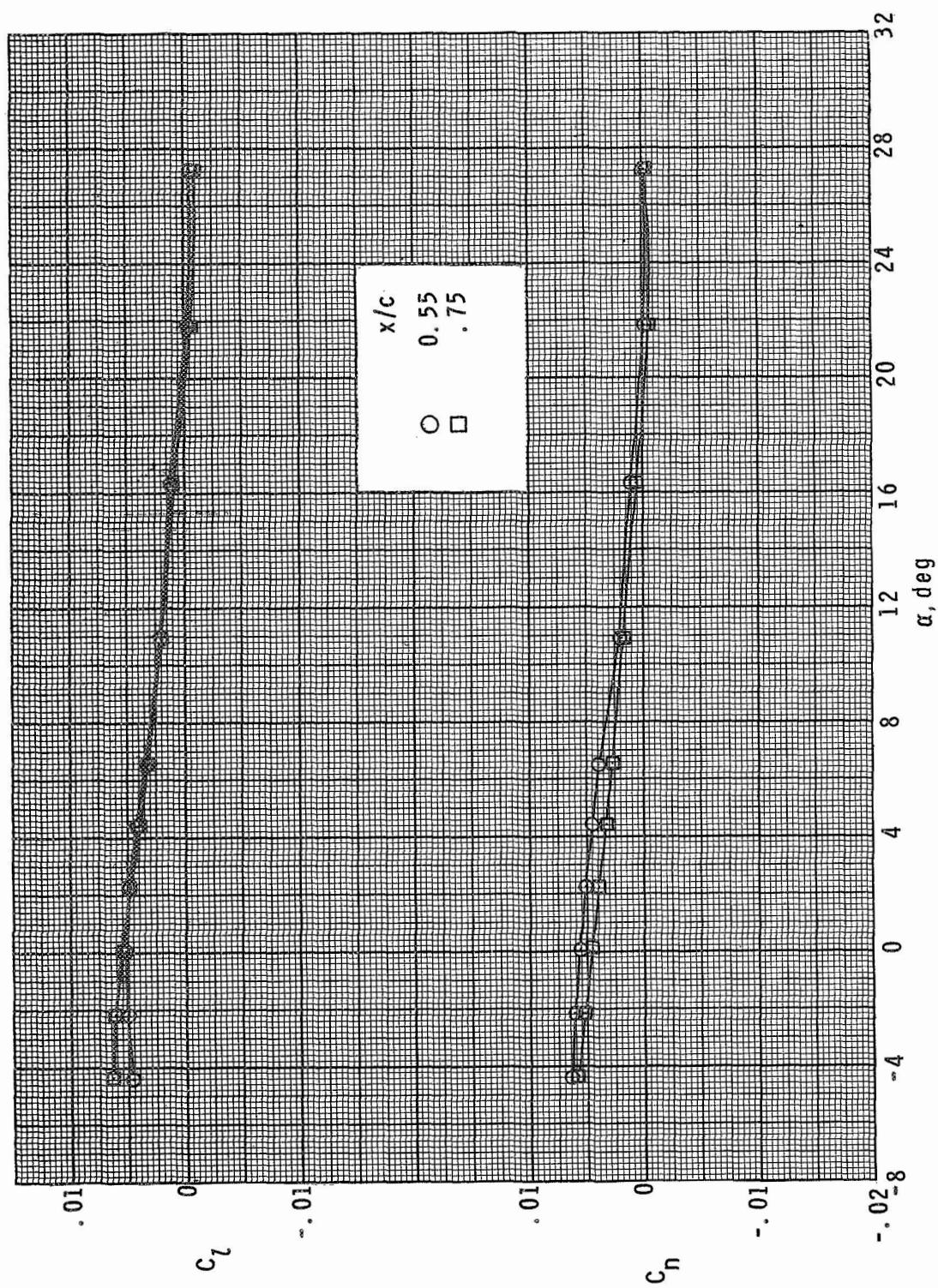
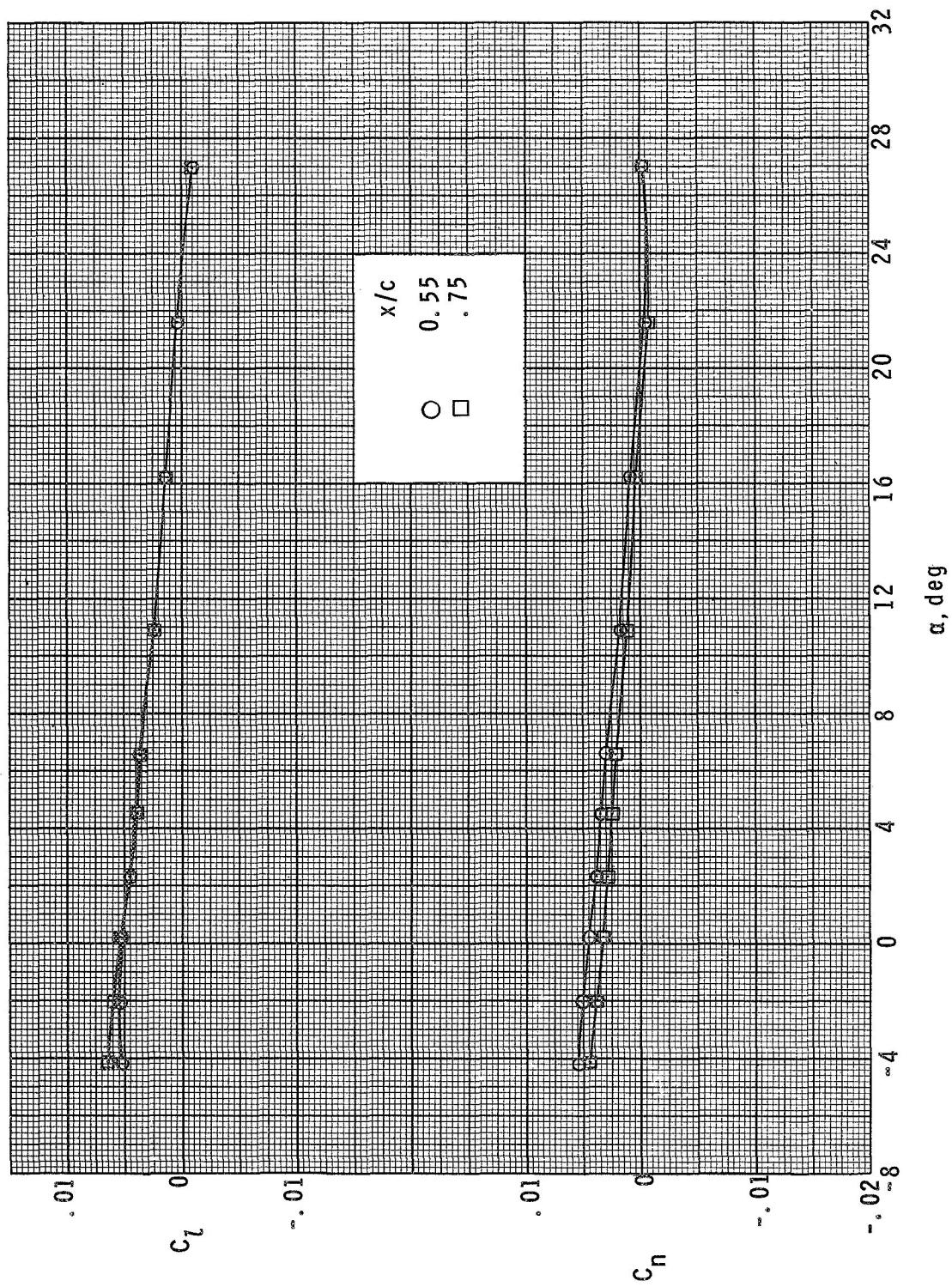
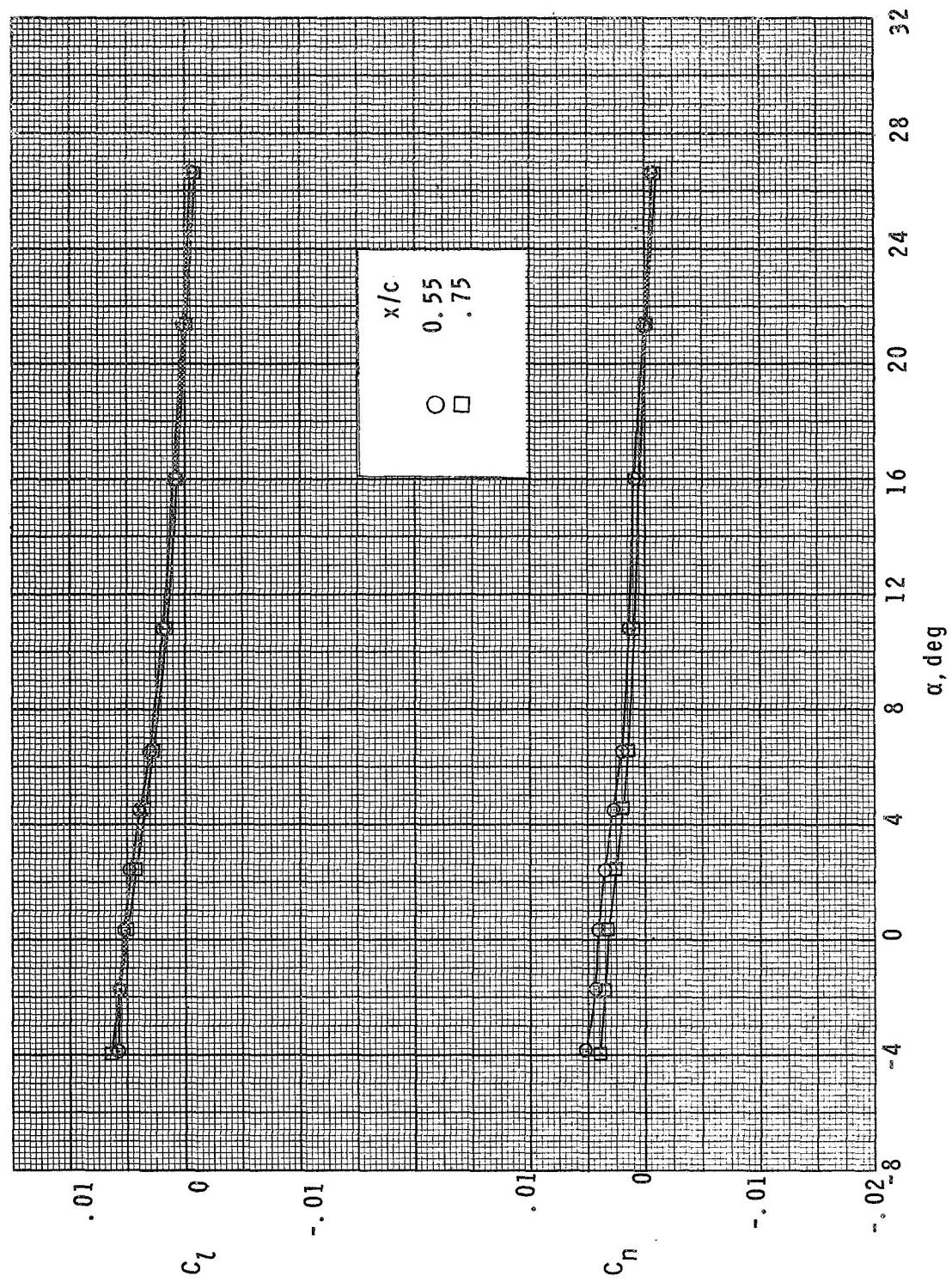


Figure 4.- Effect of chordwise spoiler location with 55° swept wing. $h/c = 0.09$; span, $0.5b/2$.
 (a) $M = 2.50$.



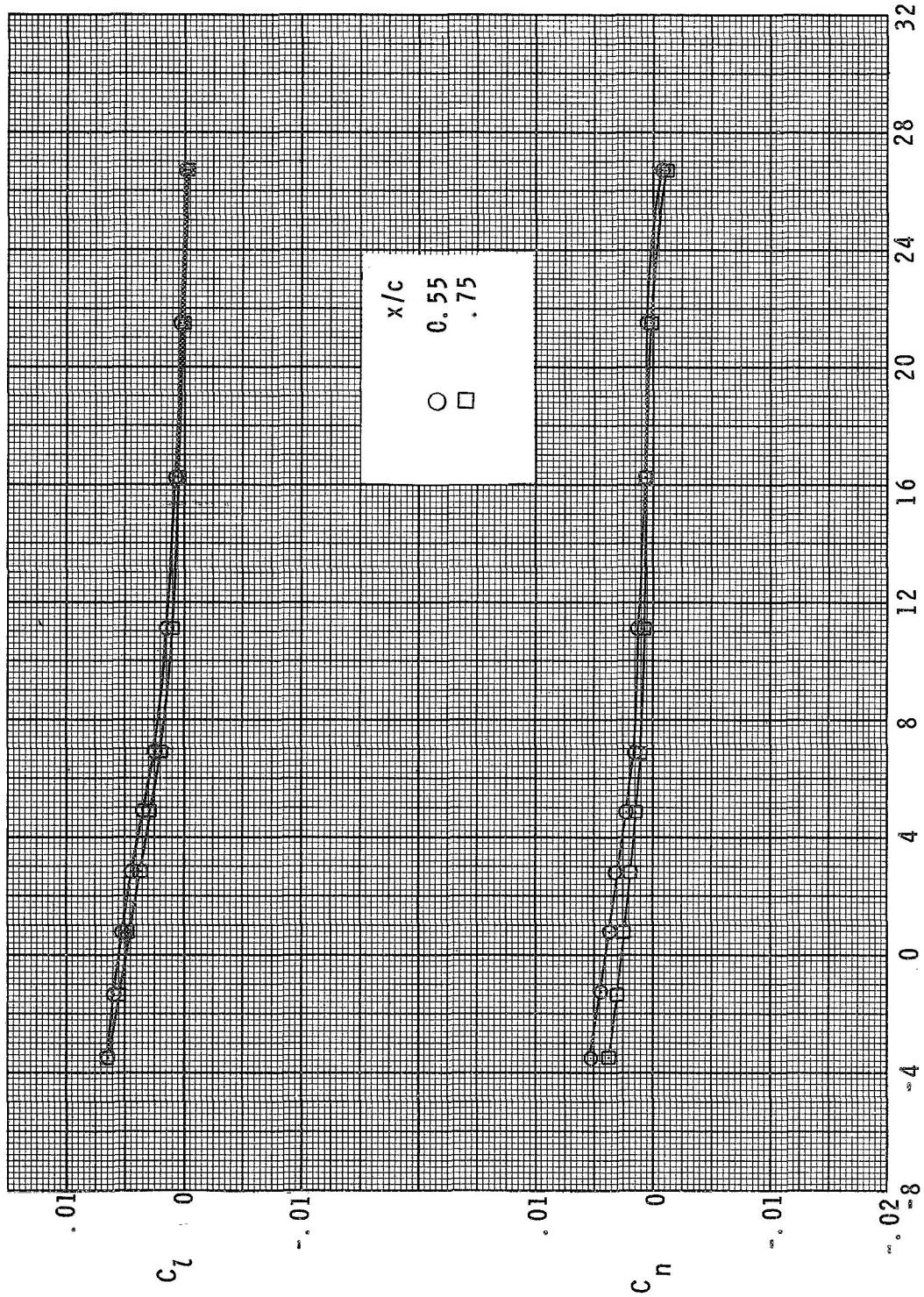
(b) $M = 2.96$.

Figure 4.- Continued.



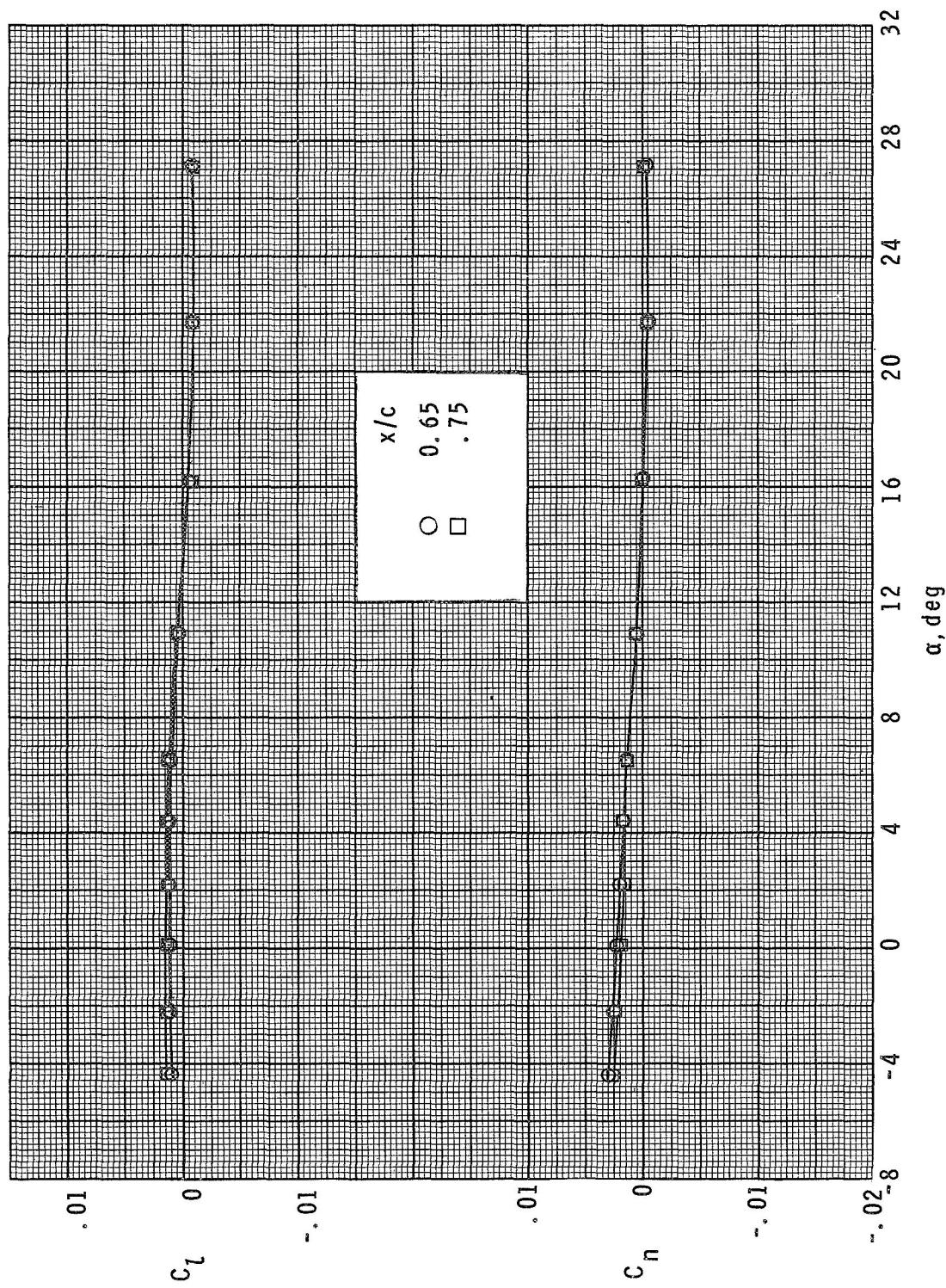
(c) $M = 3.96$.

Figure 4-- Continued.



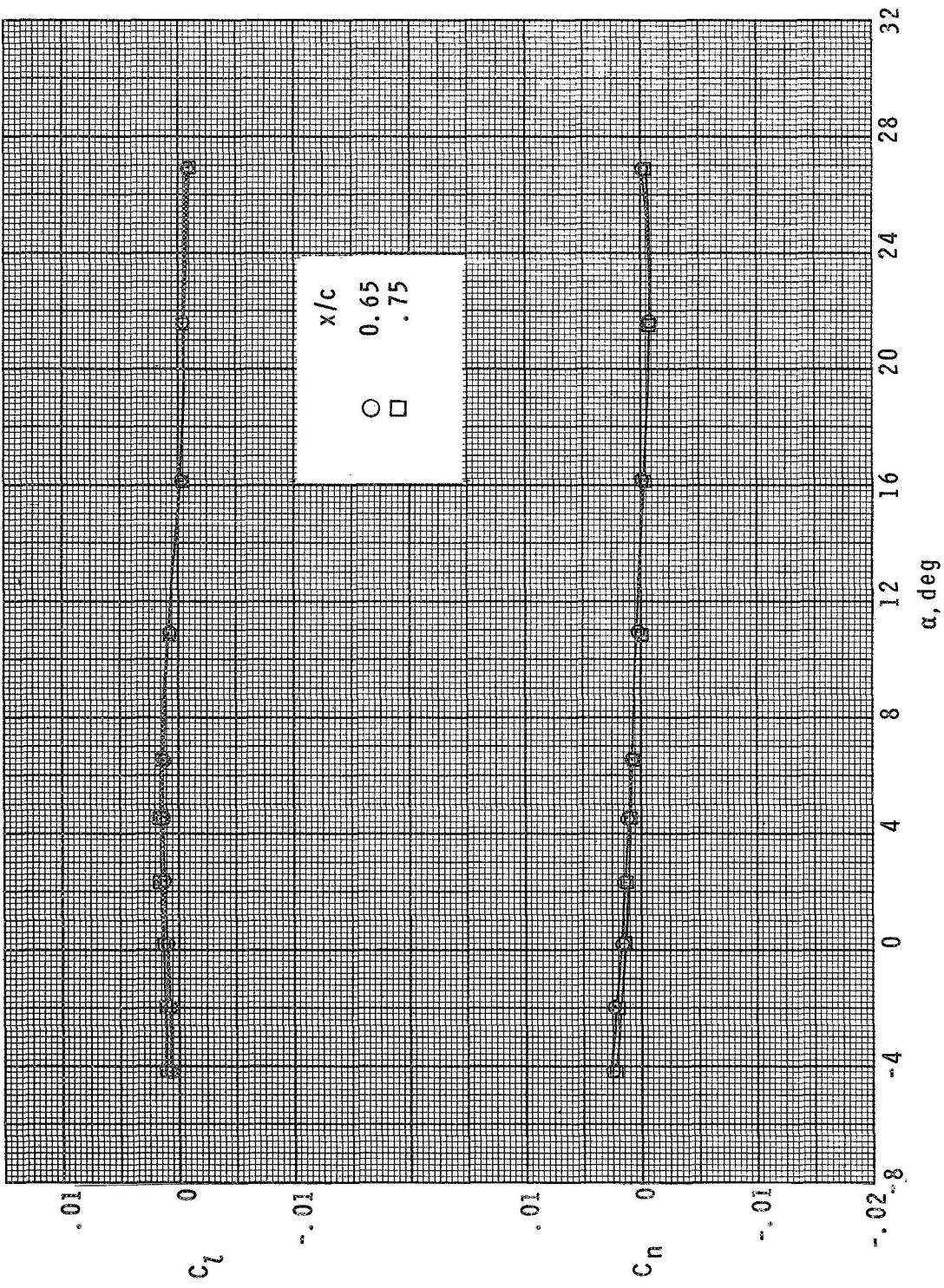
(d) $M = 4.63$.

Figure 4.- Concluded.



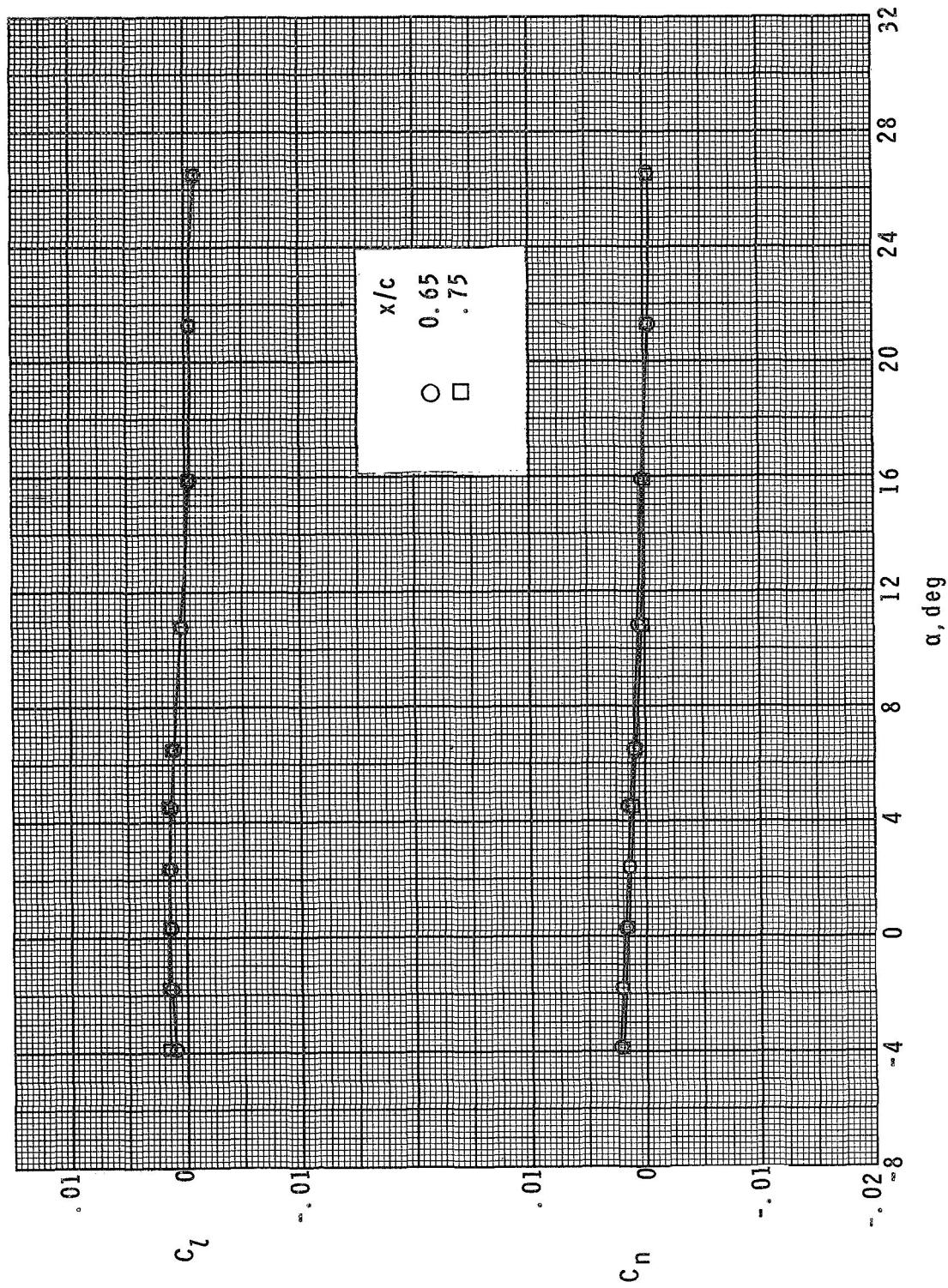
(a) $M = 2.50$.

Figure 5.- Effect of chordwise spoiler location with 75° swept wing. $h/c = 0.09$; span, $0.5b/2$.



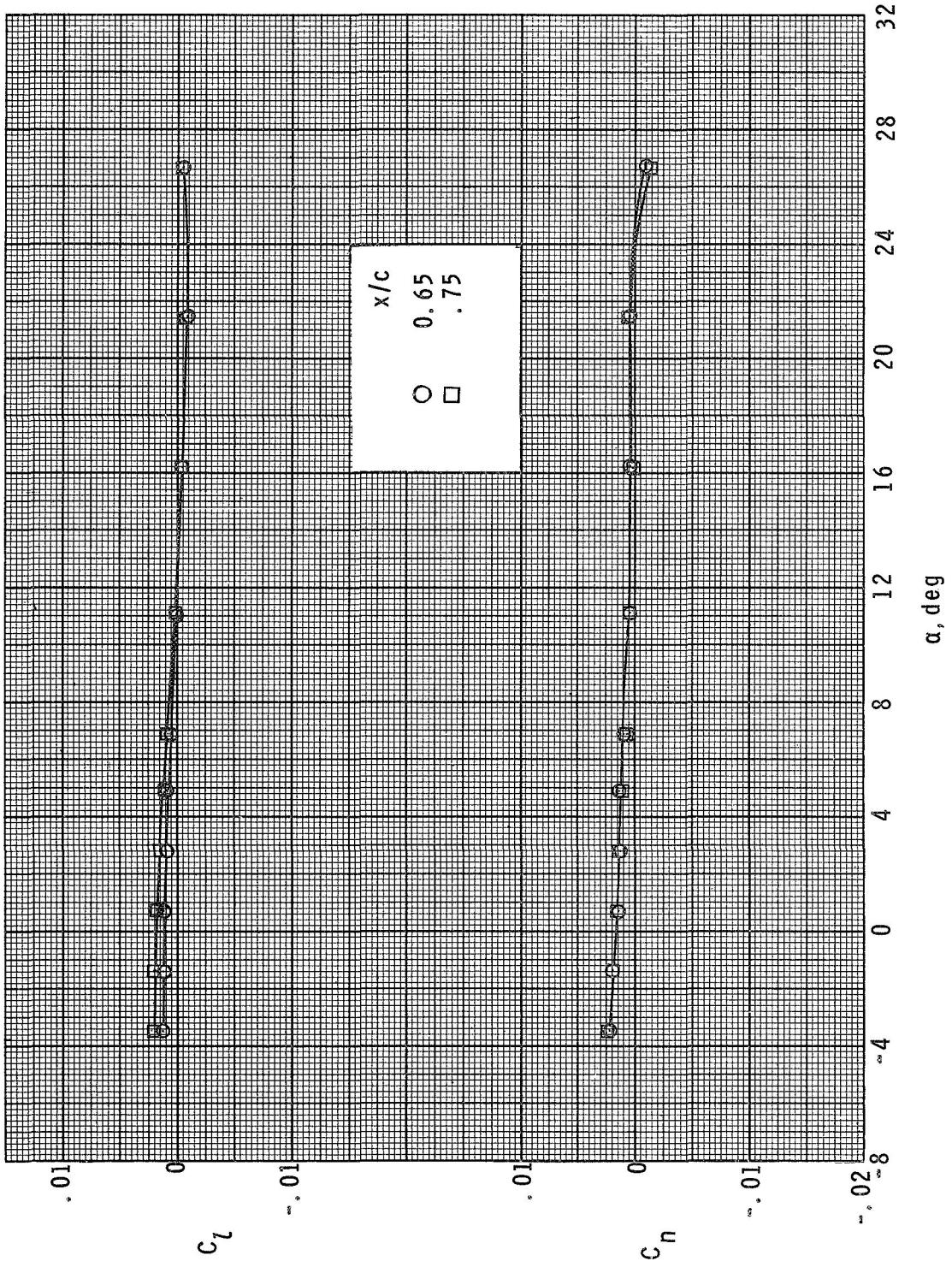
(b) $M = 2.96$.

Figure 5.- Continued.



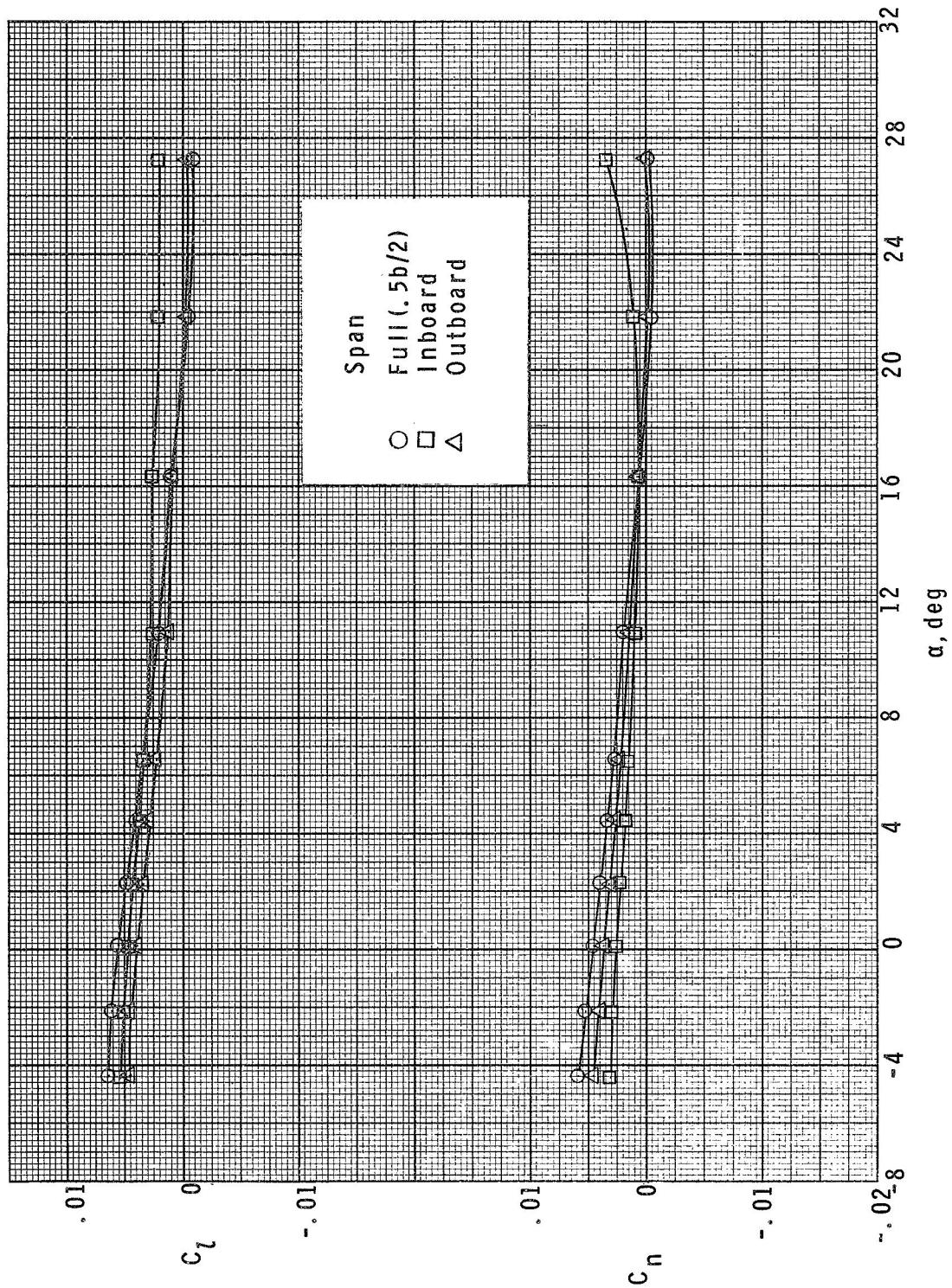
(c) $M = 3.96$.

Figure 5.- Continued.



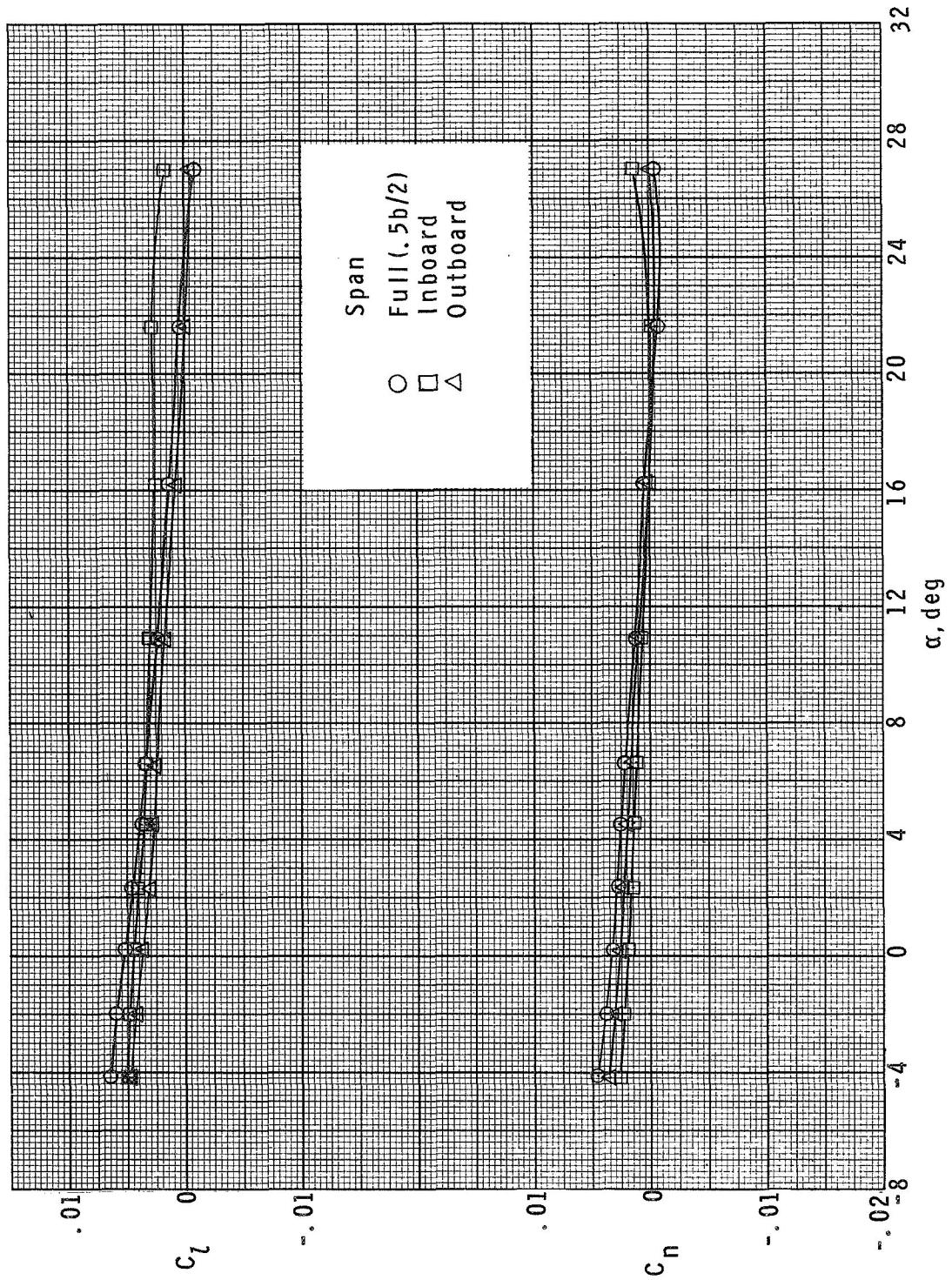
(d) $M = 4.63$.

Figure 5.- Concluded.



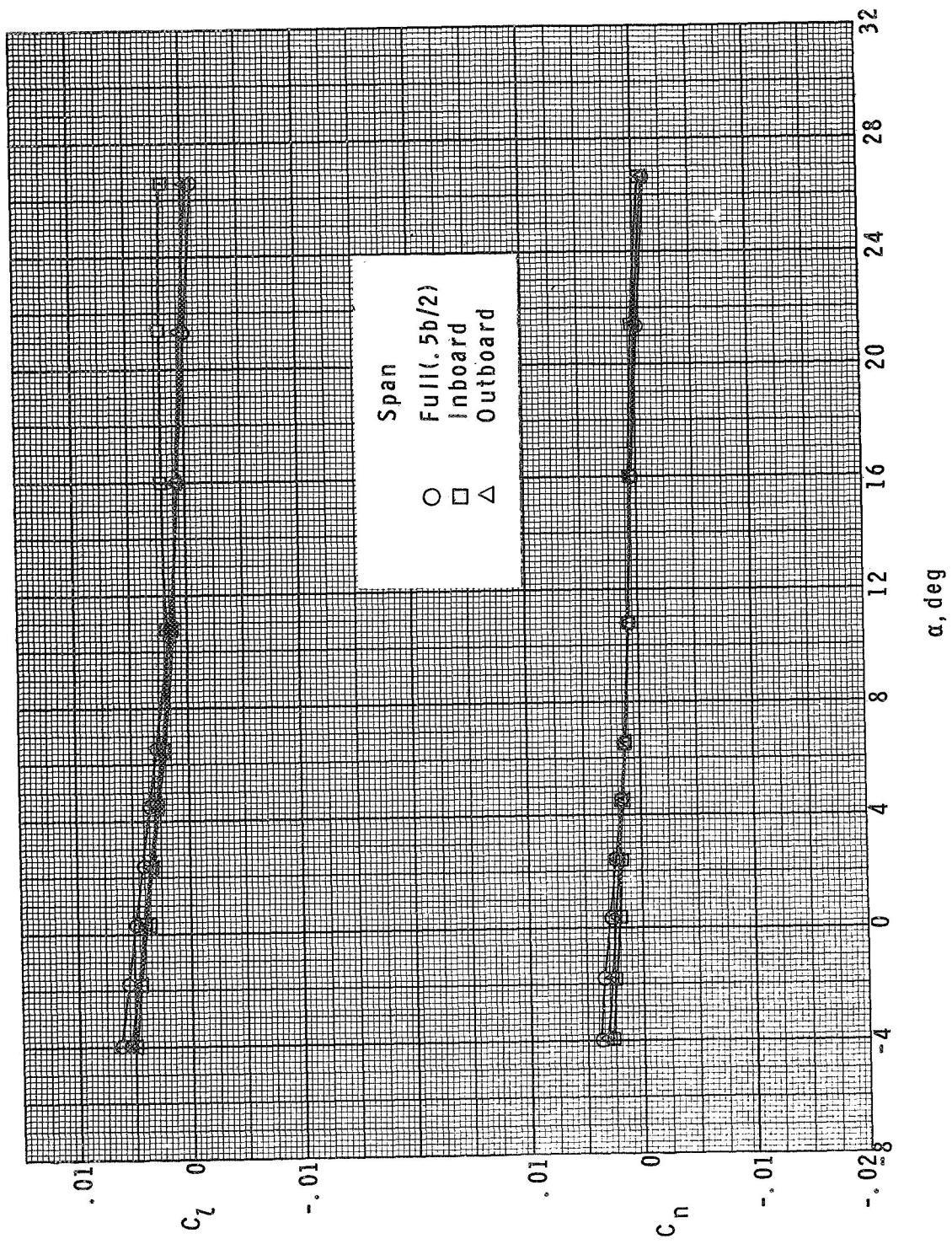
(a) $M = 2.50$.

Figure 6.- Effect of spoiler span and spanwise location with 55° swept wing. $h/c = 0.09$; $x/c = 0.75$.



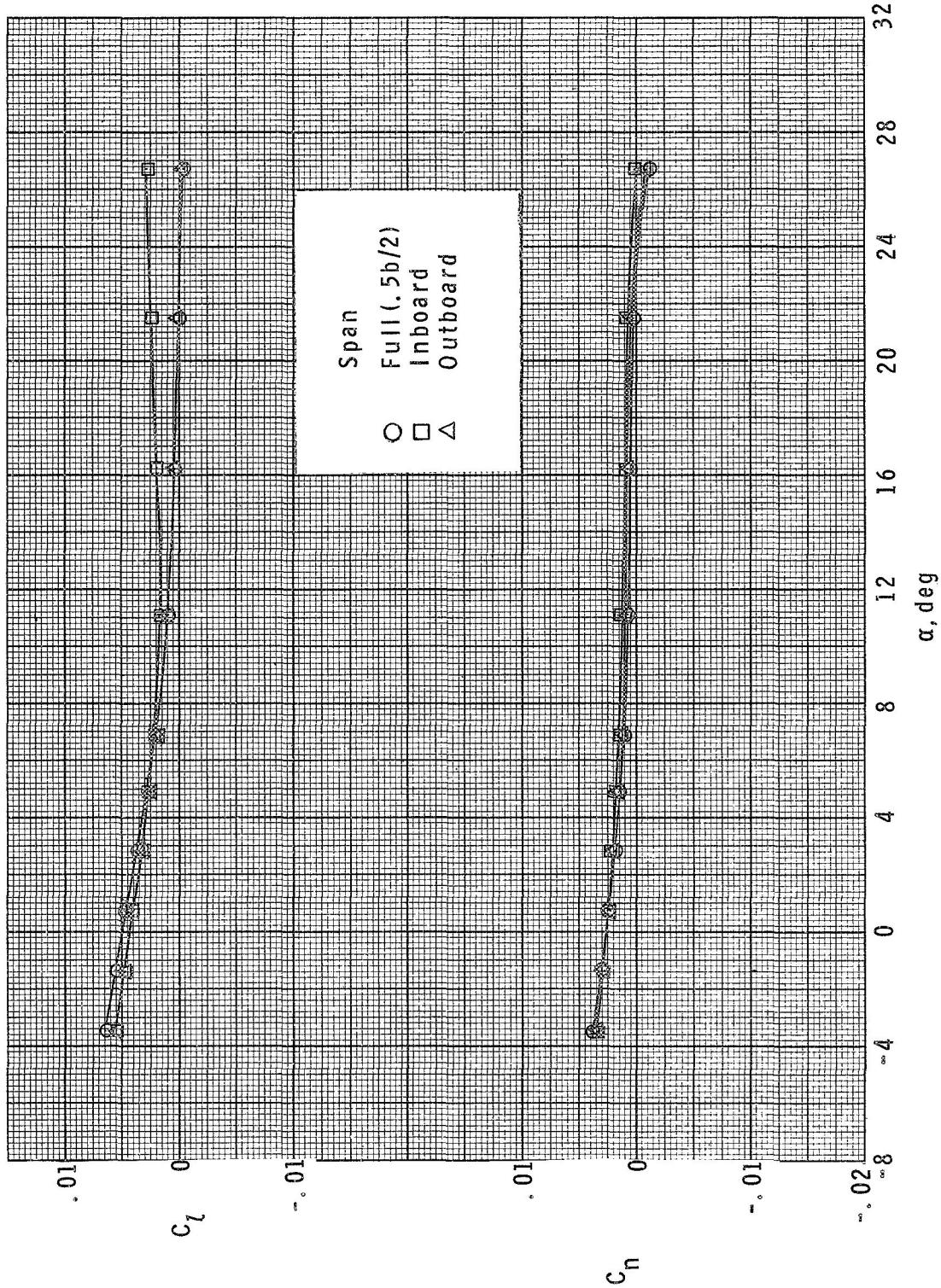
(b) $M = 2.96$.

Figure 6. -- Continued.



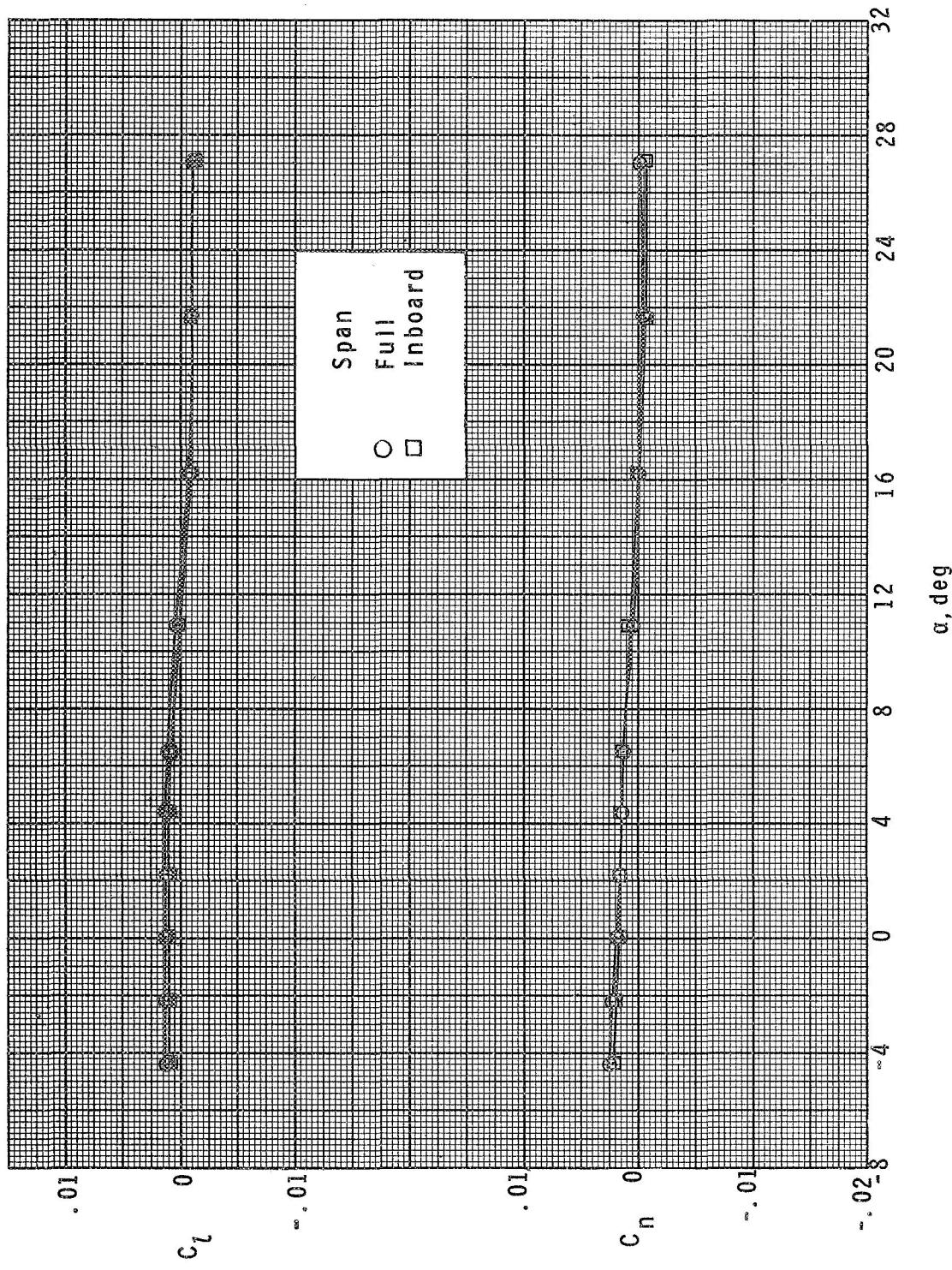
(c) $M = 3.96$.

Figure 6.- Continued.



(d) $M = 4.63$.

Figure 6.- Concluded.



(a) $M = 2.50$.
 Figure 7 - Effect of spoiler span and spanwise location with 75° swept wing. $h/c = 0.09$; $x/c = 0.75$.

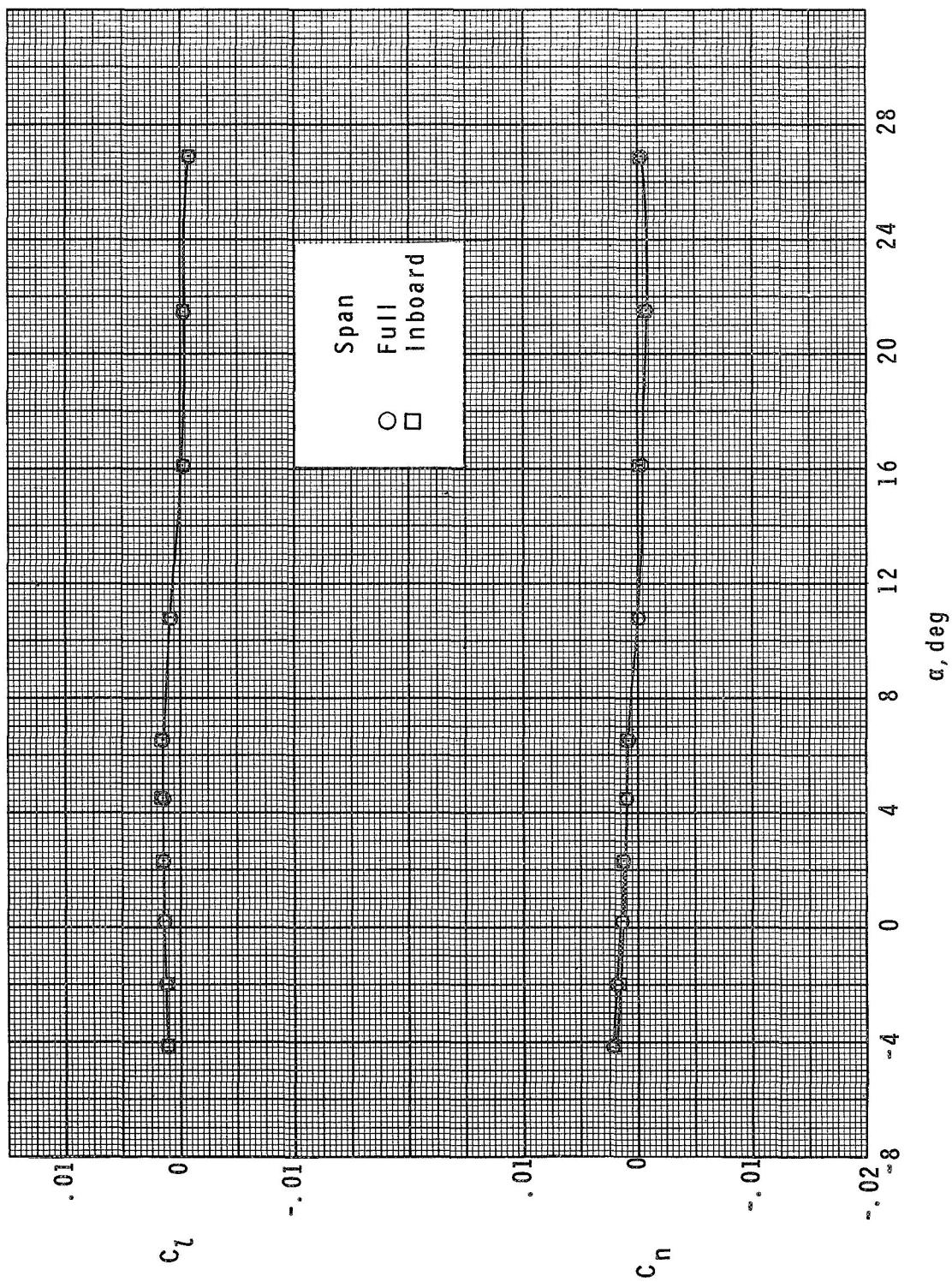
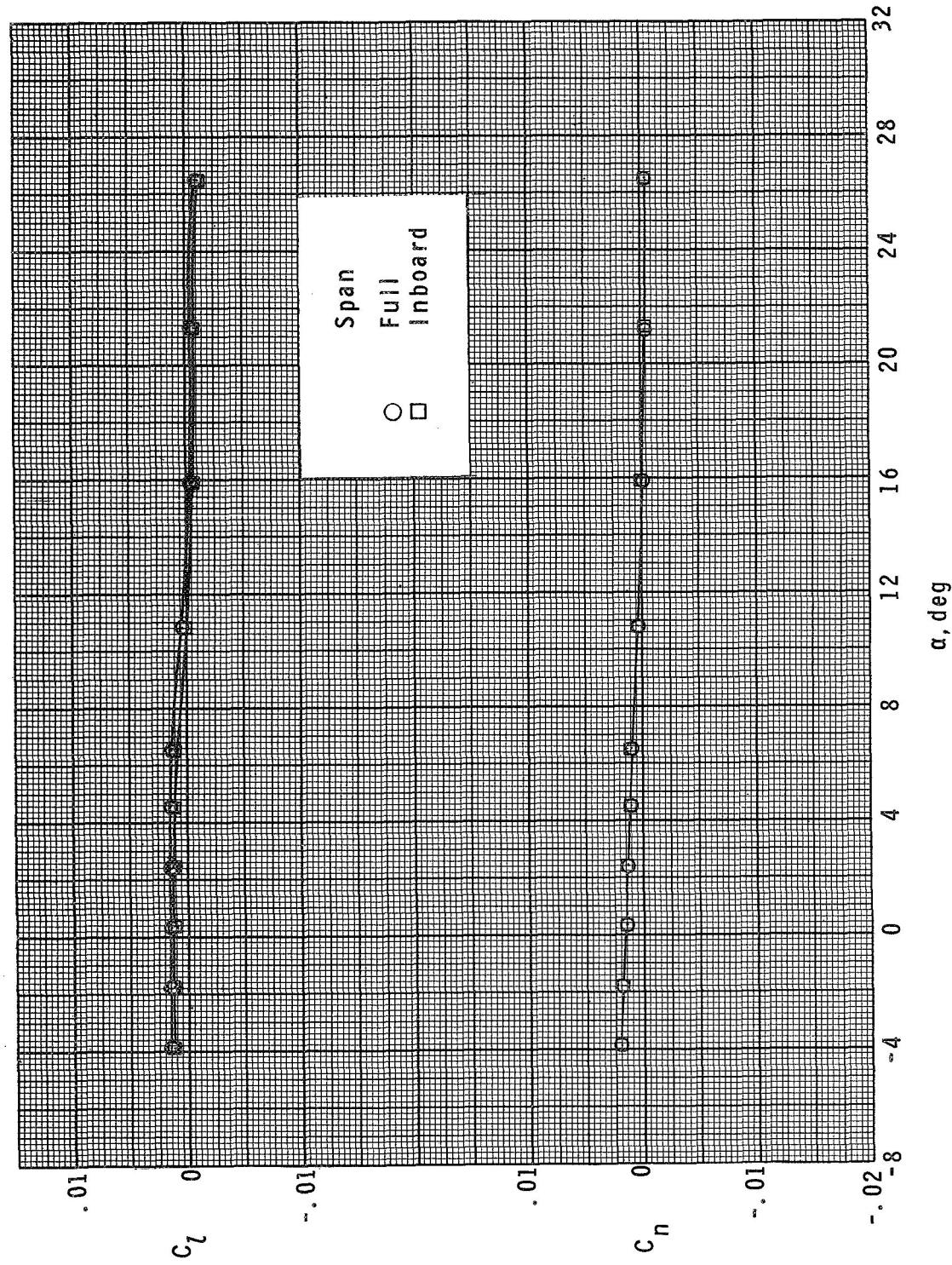


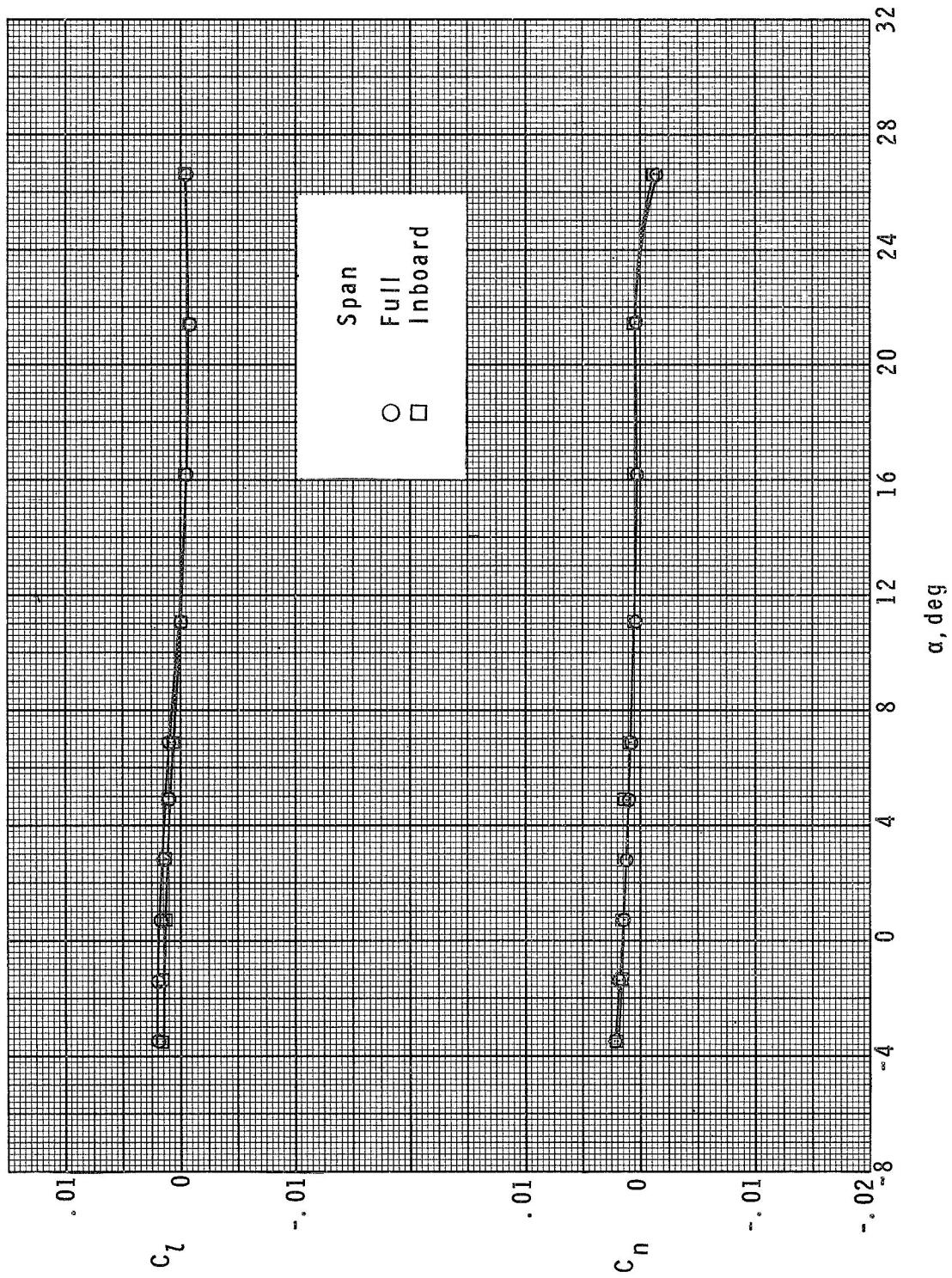
Figure 7.- Continued.

(b) $M = 2.96$.



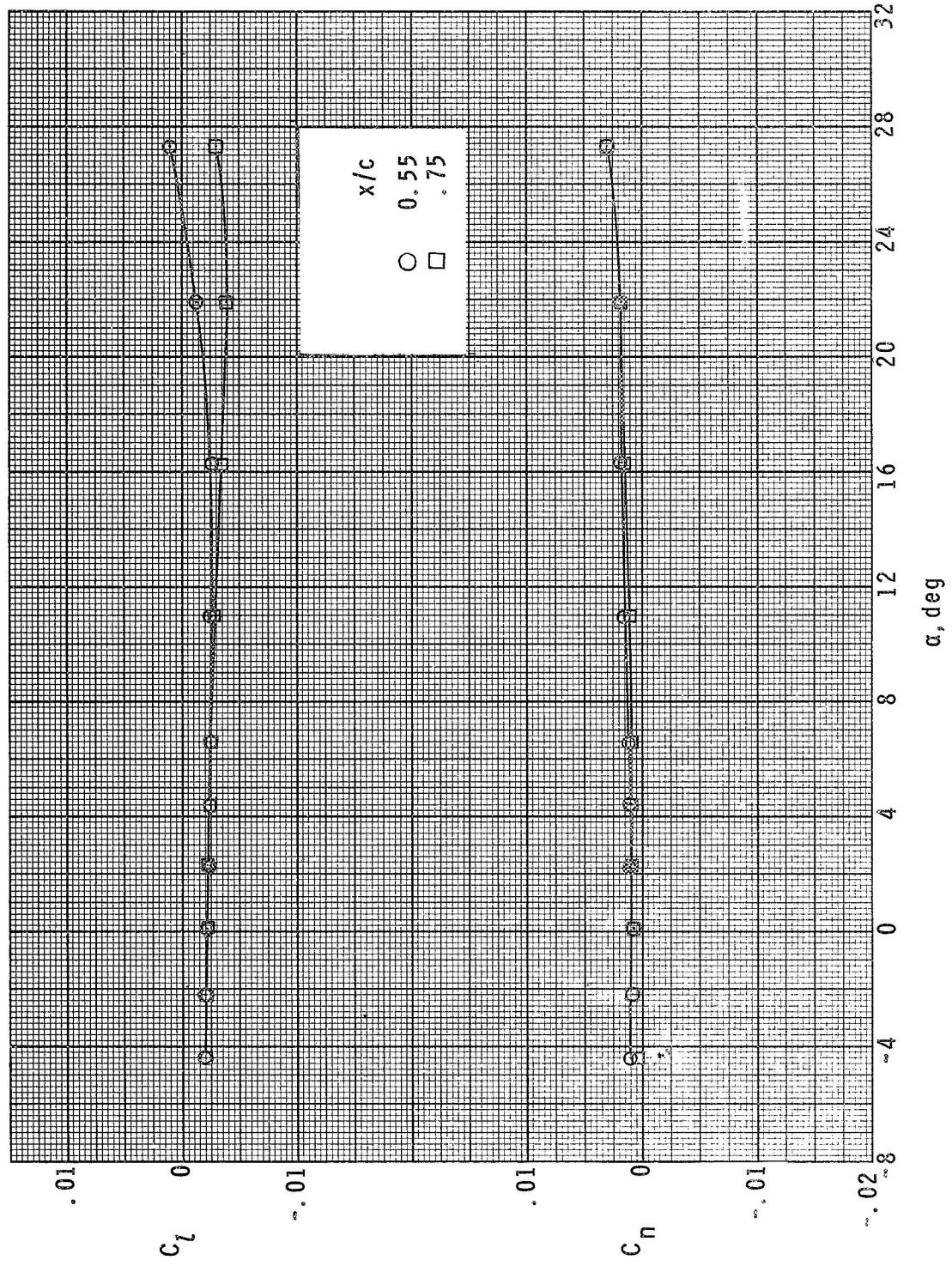
(c) $M = 3.96$.

Figure 7.- Continued.



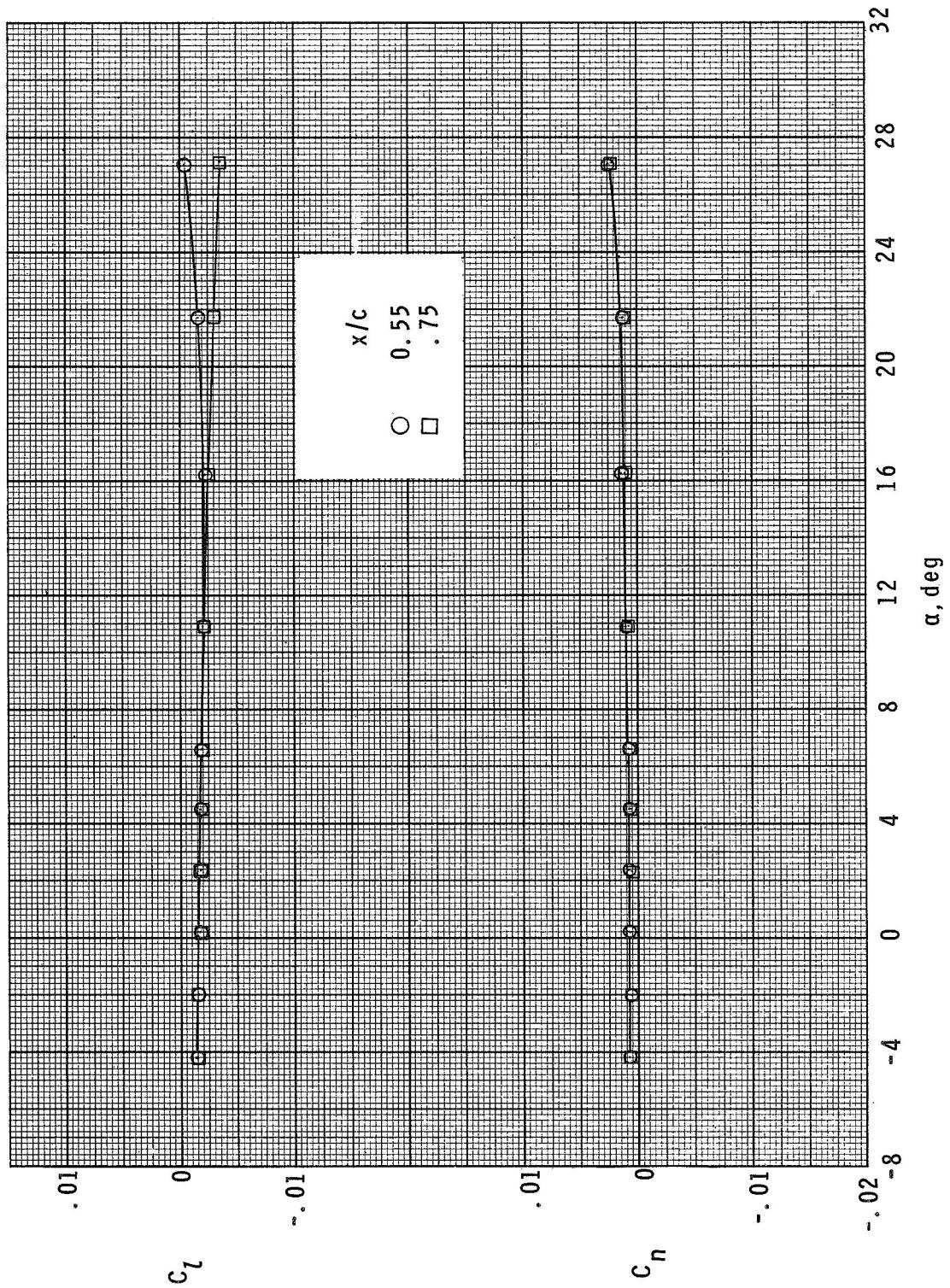
(d) $M = 4.63$.

Figure 7. - Concluded.



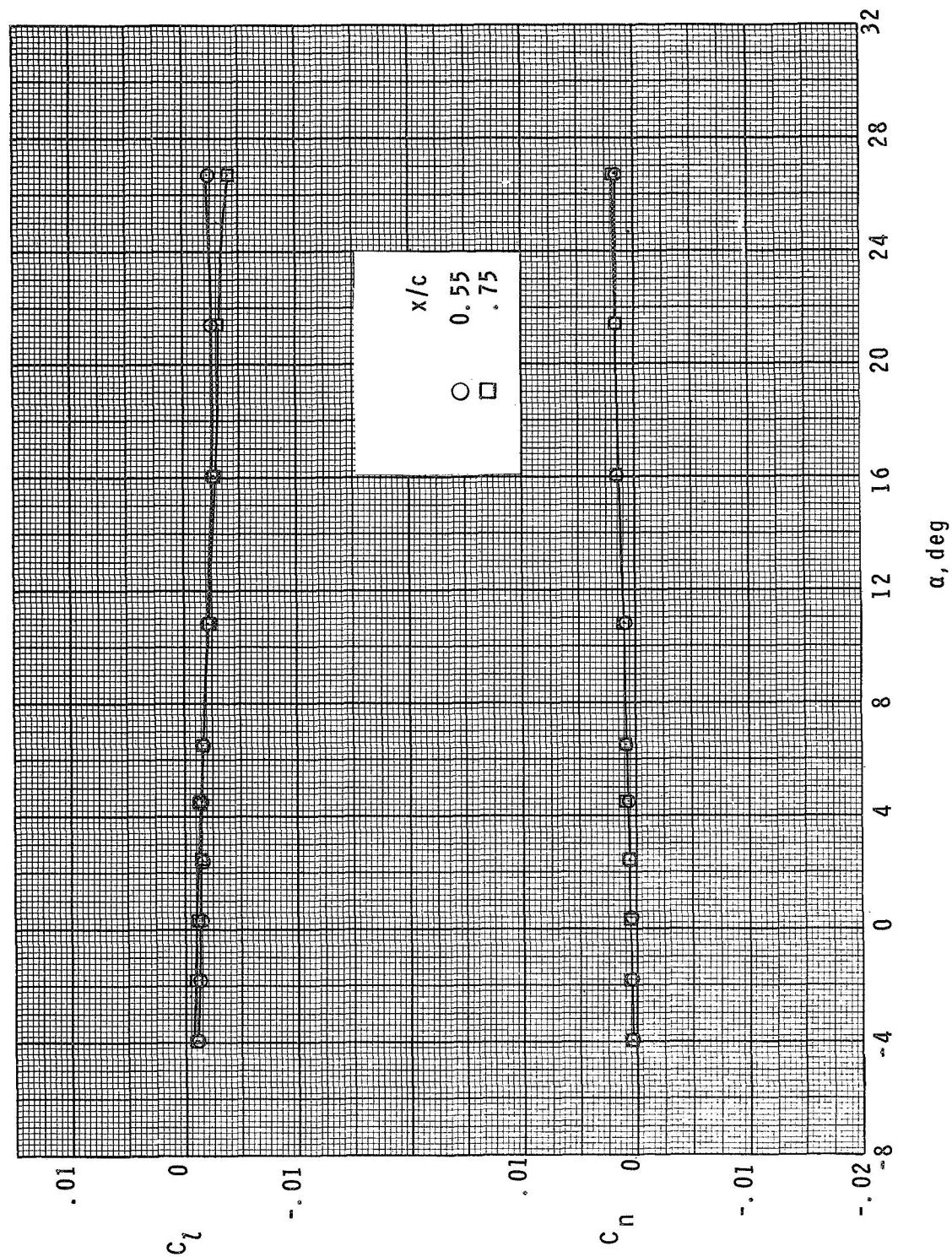
(a) $M = 2.50$.

Figure 8. Effect of chordwise location of lower surface spoiler with 55° swept wing. $h/c = 0.03$; span, $0.5b/2$.



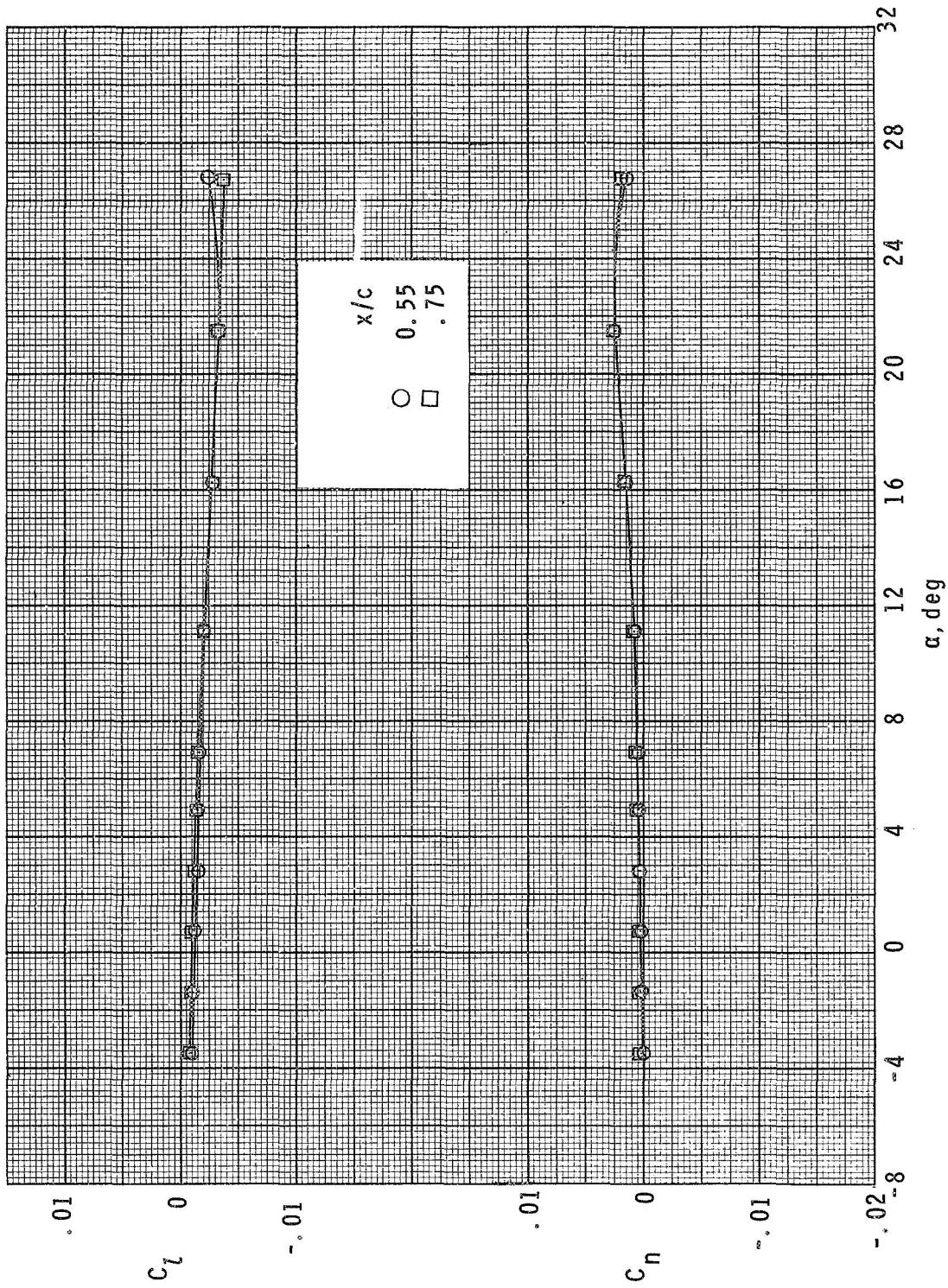
(b) $M = 2.96$.

Figure 8.- Continued.



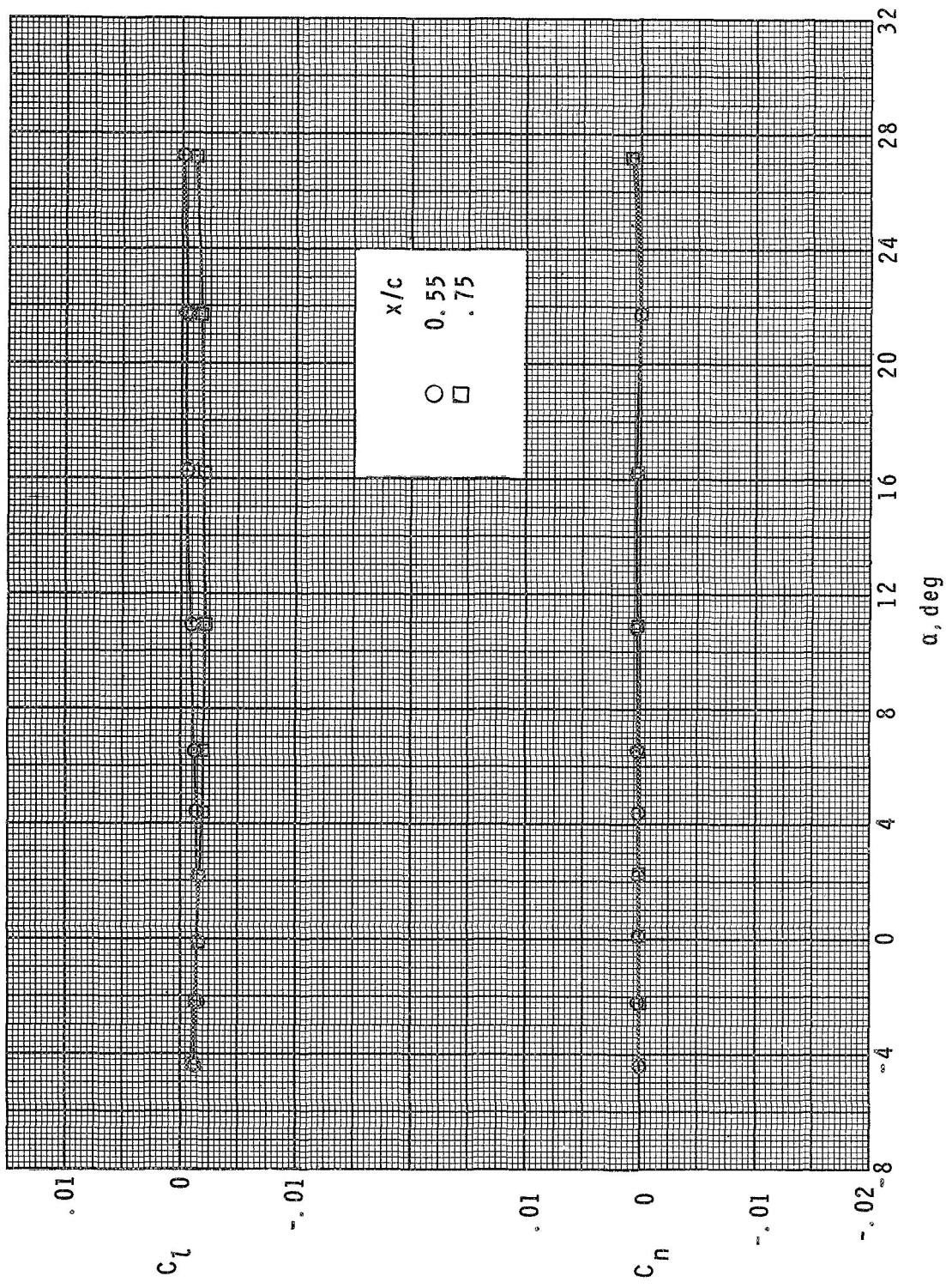
(c) $M = 3.96$.

Figure 8.- Continued.



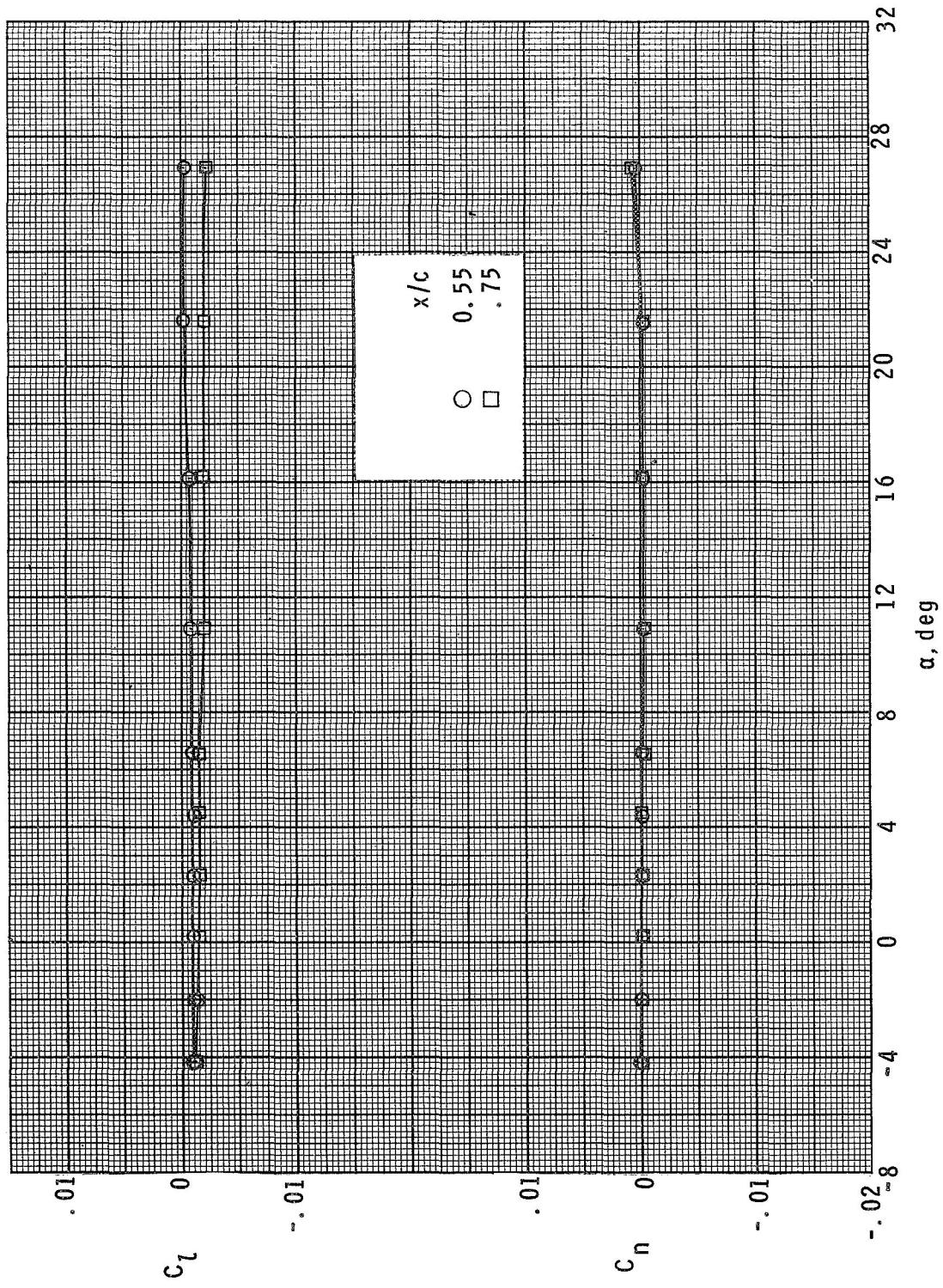
(d) $M = 4.63$.

Figure 8.- Concluded.



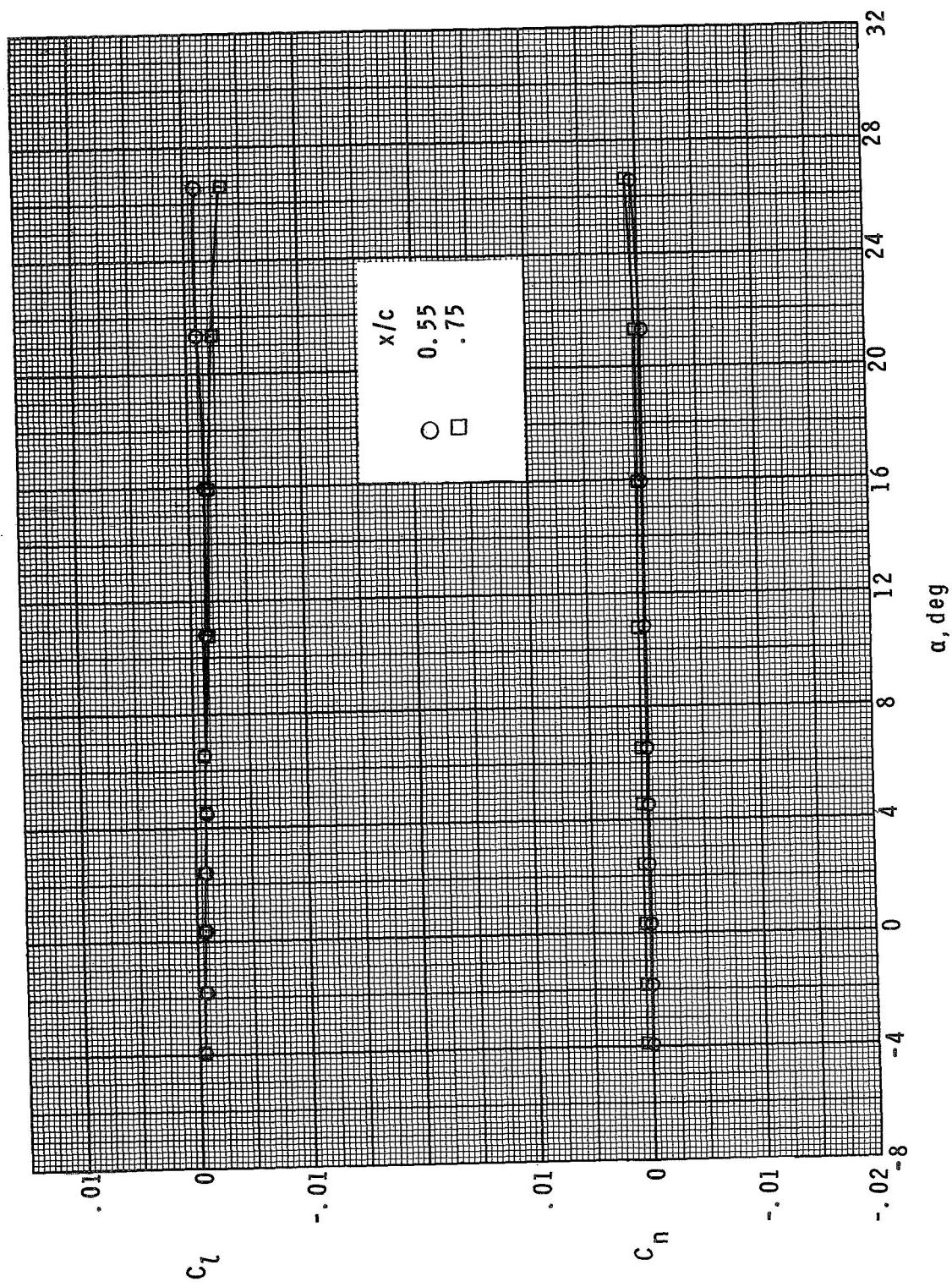
(a) $M = 2.50$.

Figure 9. - Effect of chordwise location of lower surface spoiler with 75° swept wing. $h/c = 0.03$; span, $0.5b/2$.



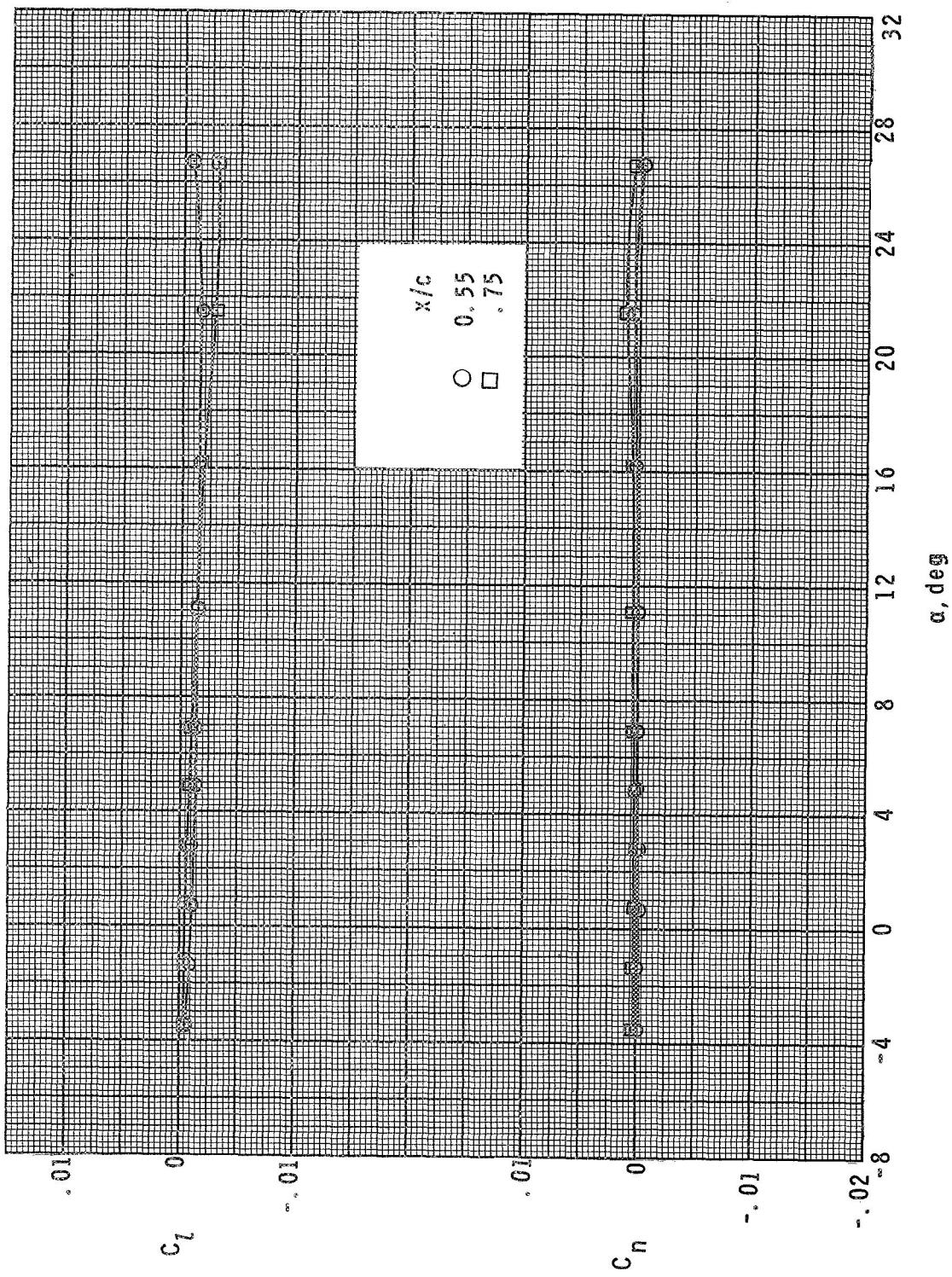
(b) $M = 2.96$.

Figure 9. - Continued.



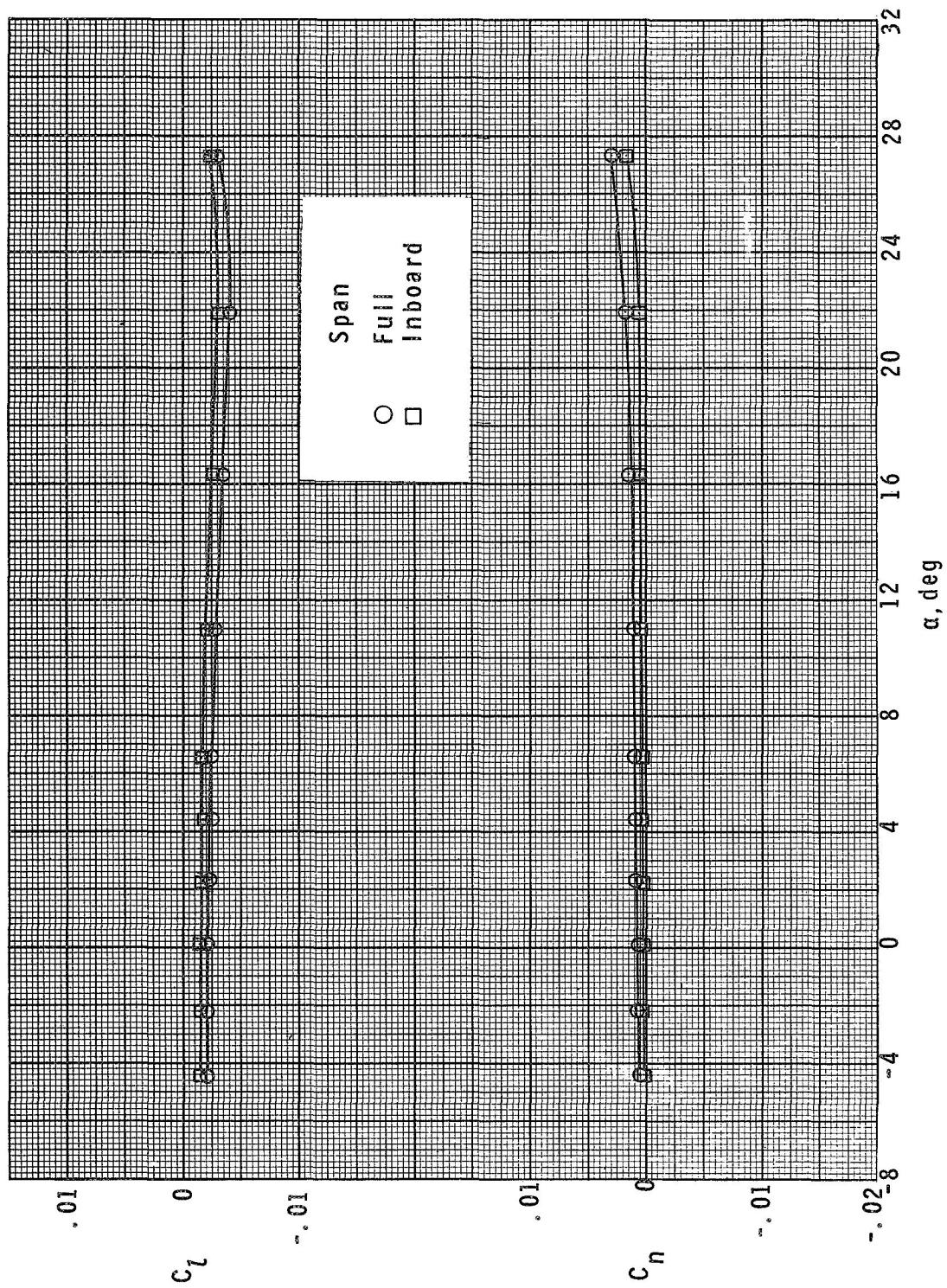
(c) $M = 3.96$.

Figure 9.- Continued.



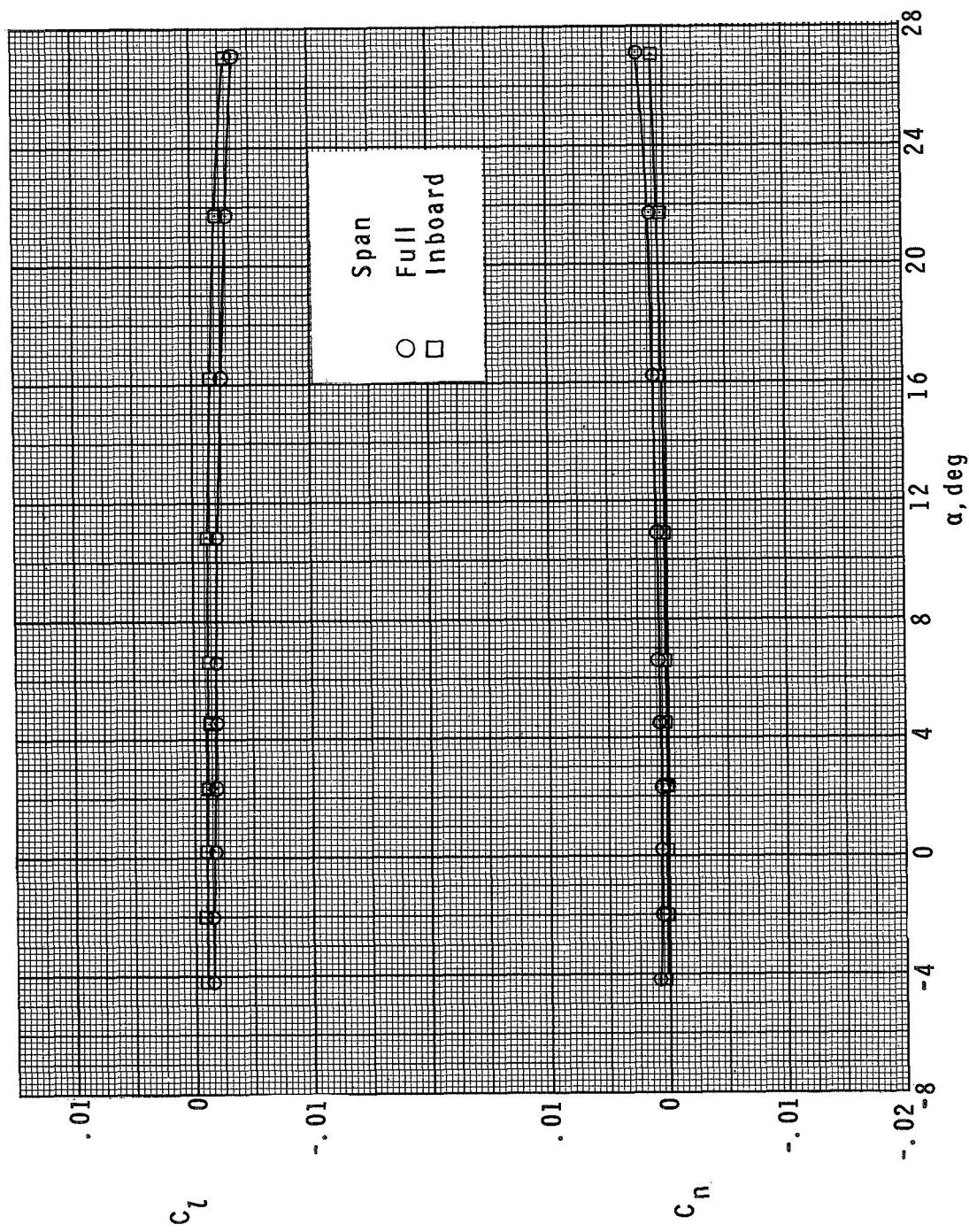
(d) $M = 4.63$.

Figure 9. -- Concluded.



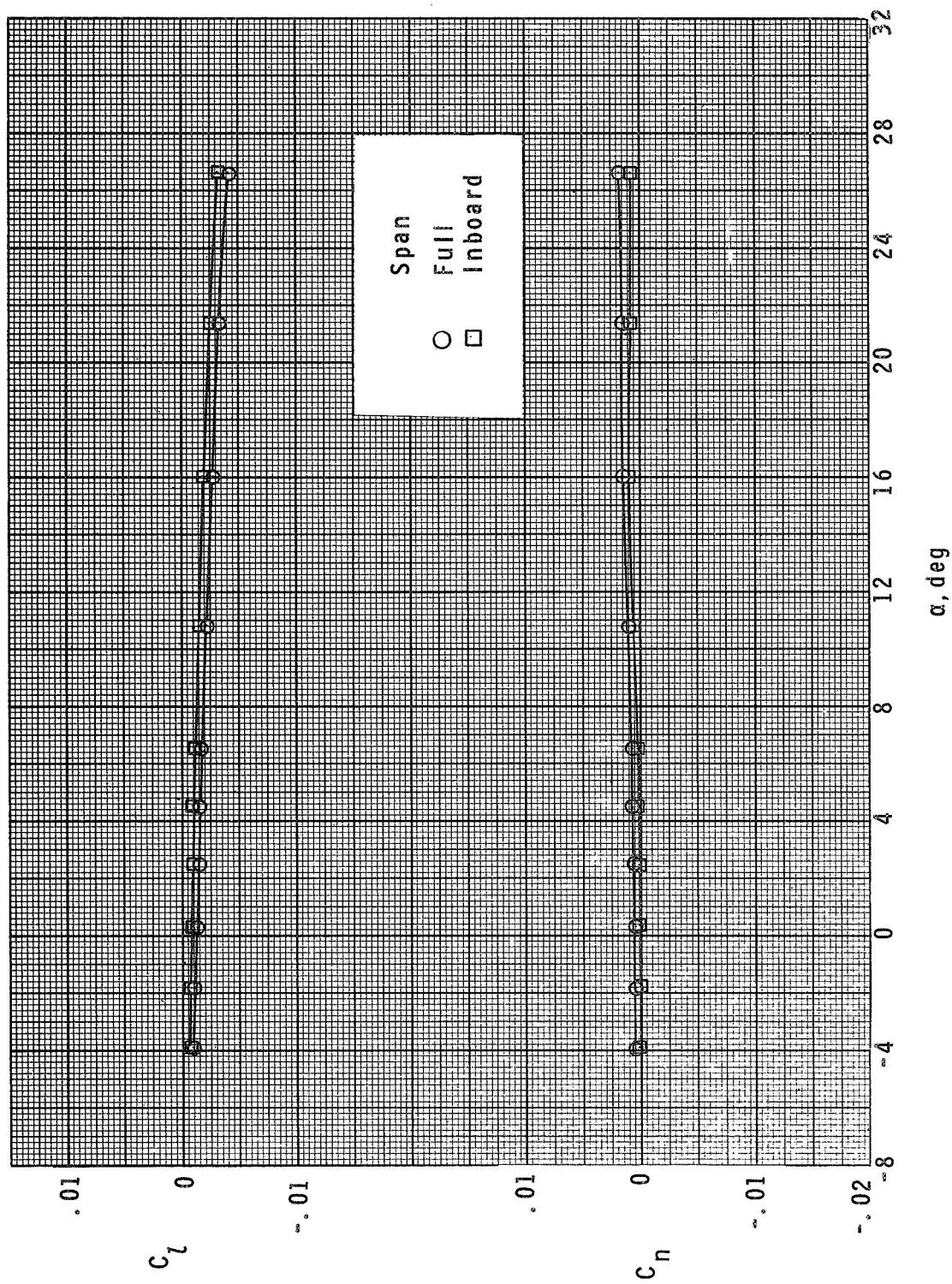
(a) $M = 2.50$.

Figure 10. - Effect of span and spanwise location of lower surface spoiler with 55° swept wing.
 $h/c = 0.03$; $x/c = 0.75$.



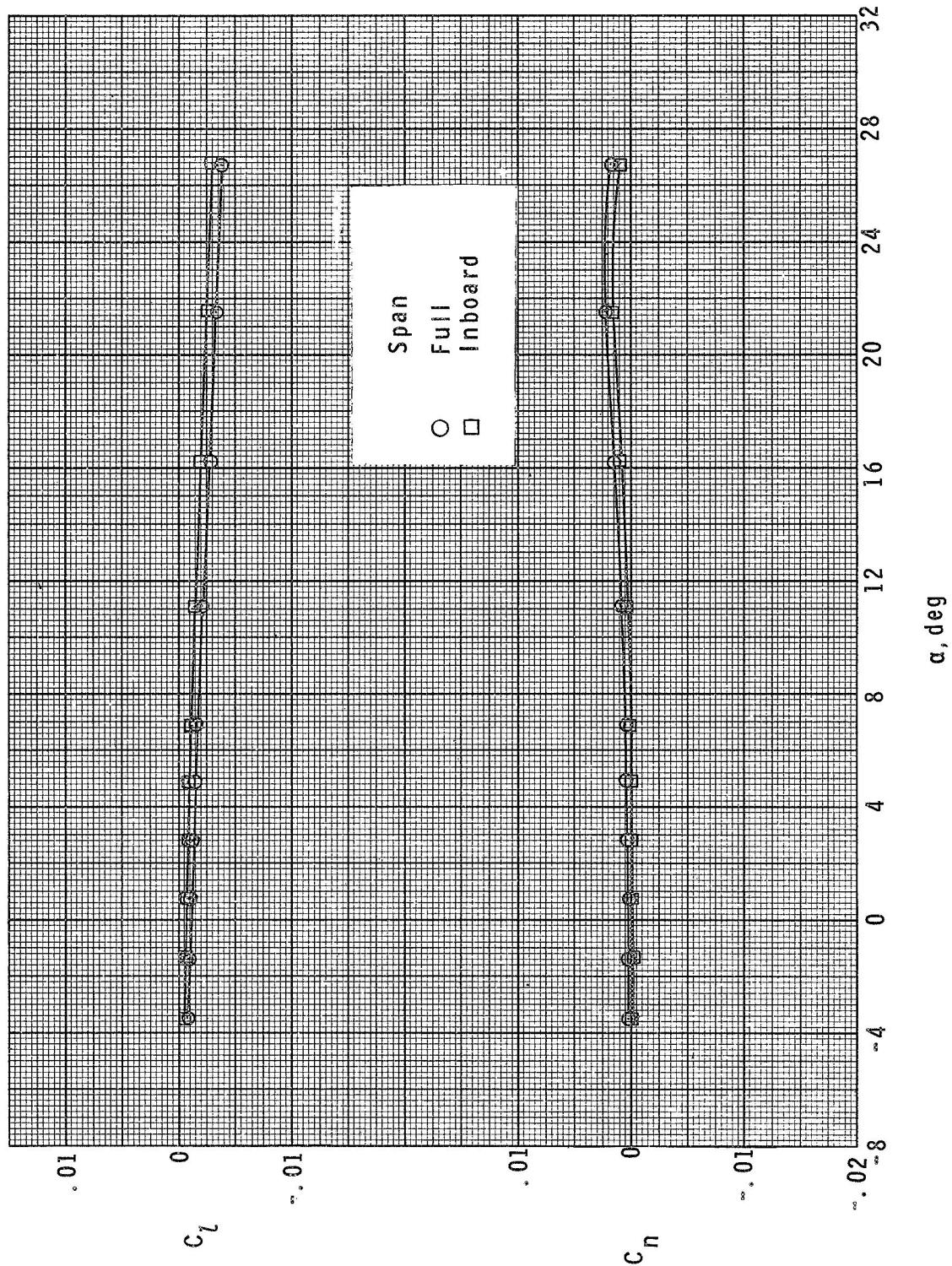
(b) $M = 2.96$.

Figure 10.7 Continued.



(c) $M = 3.96$.

Figure 10.—Continued.



(d) $M = 4.63$.

Figure 10.- Concluded.

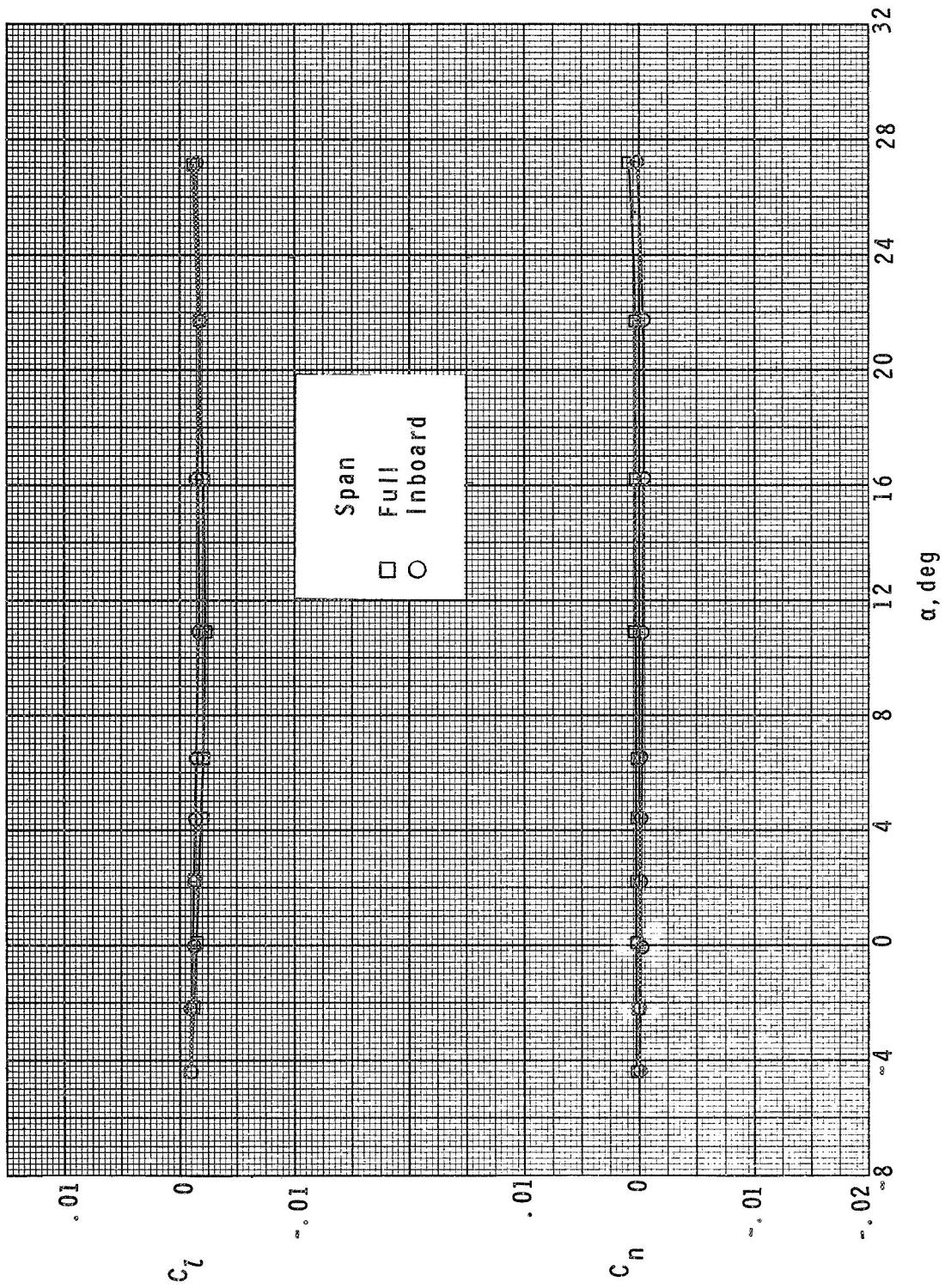
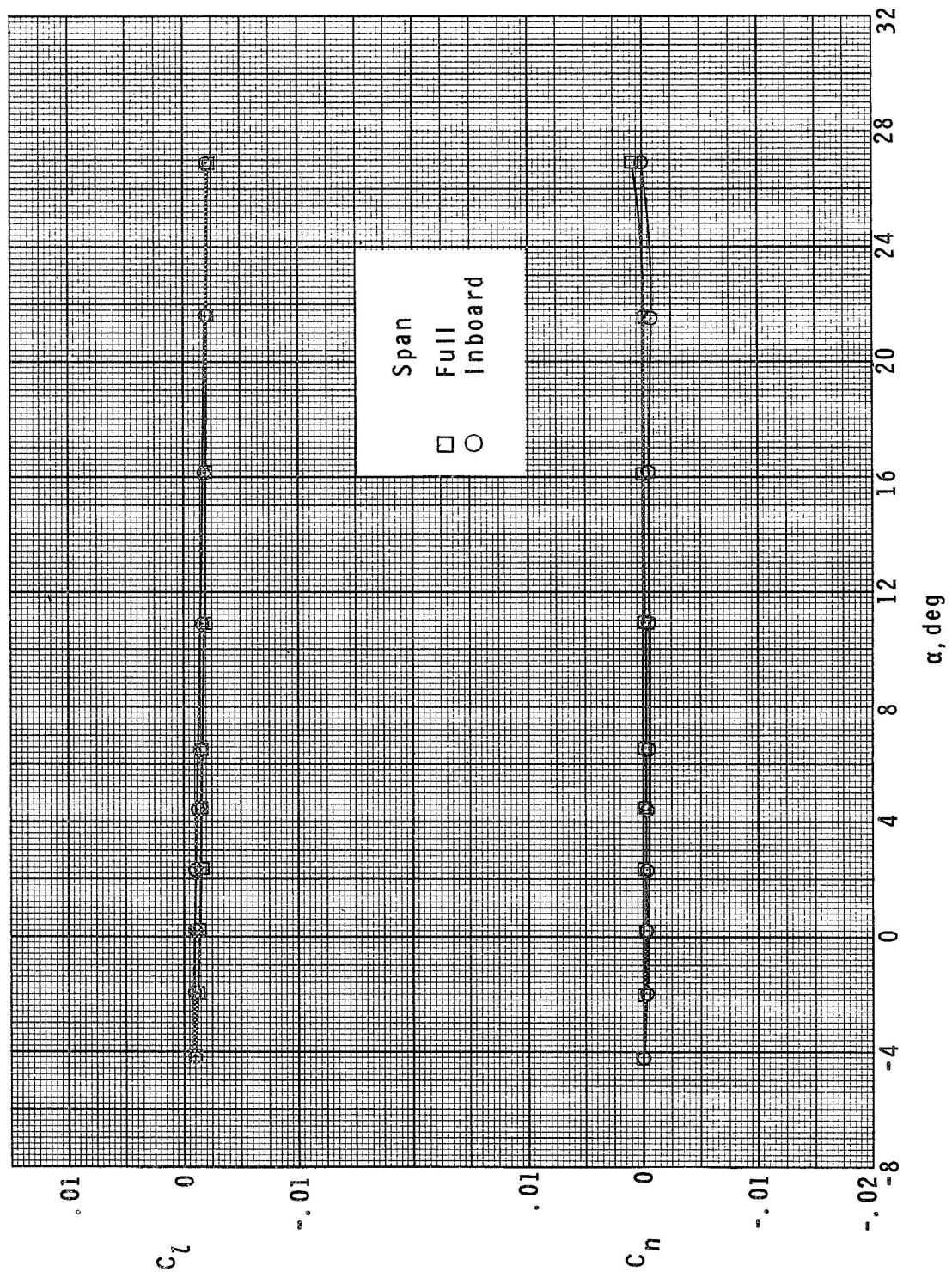
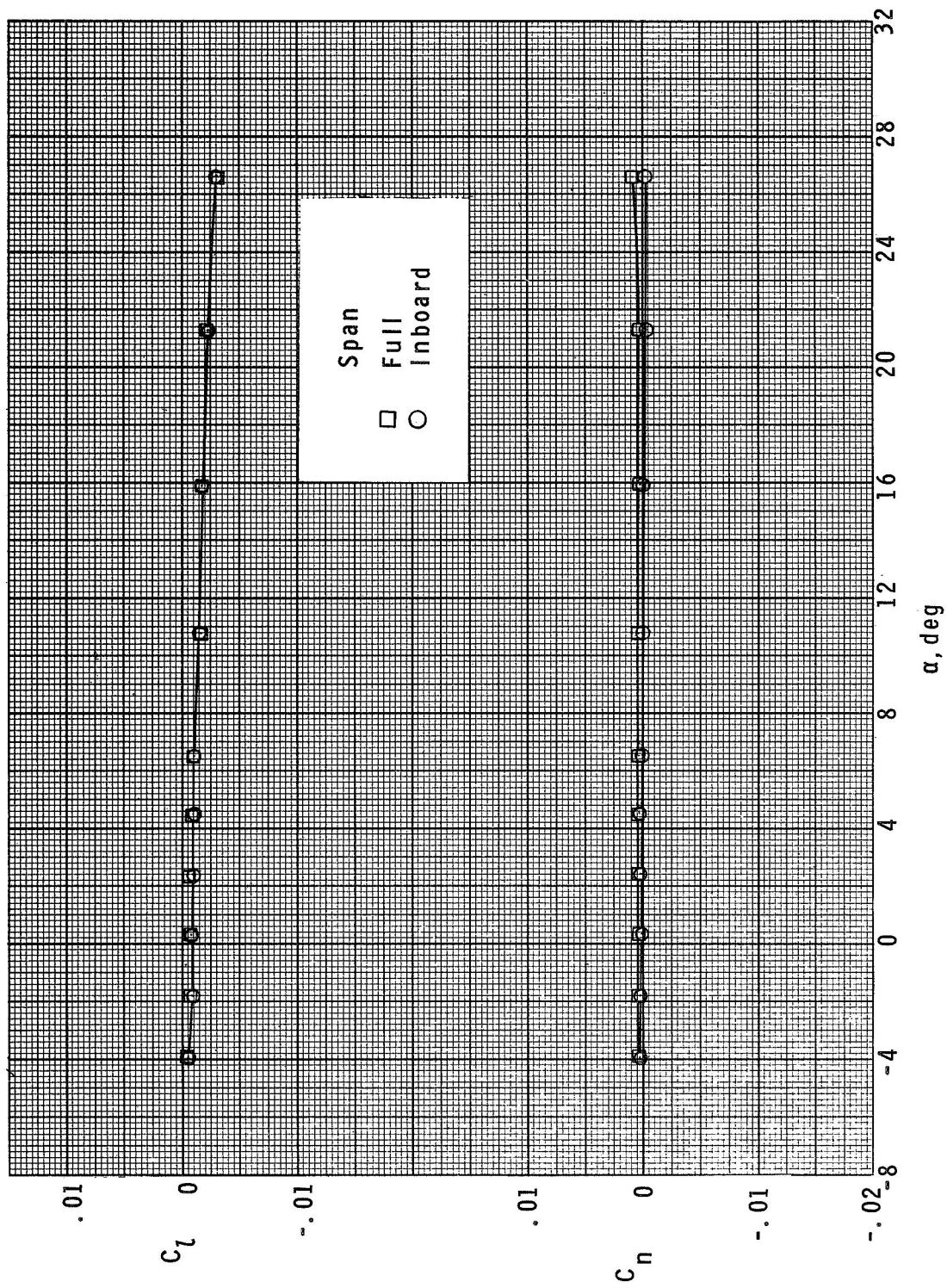


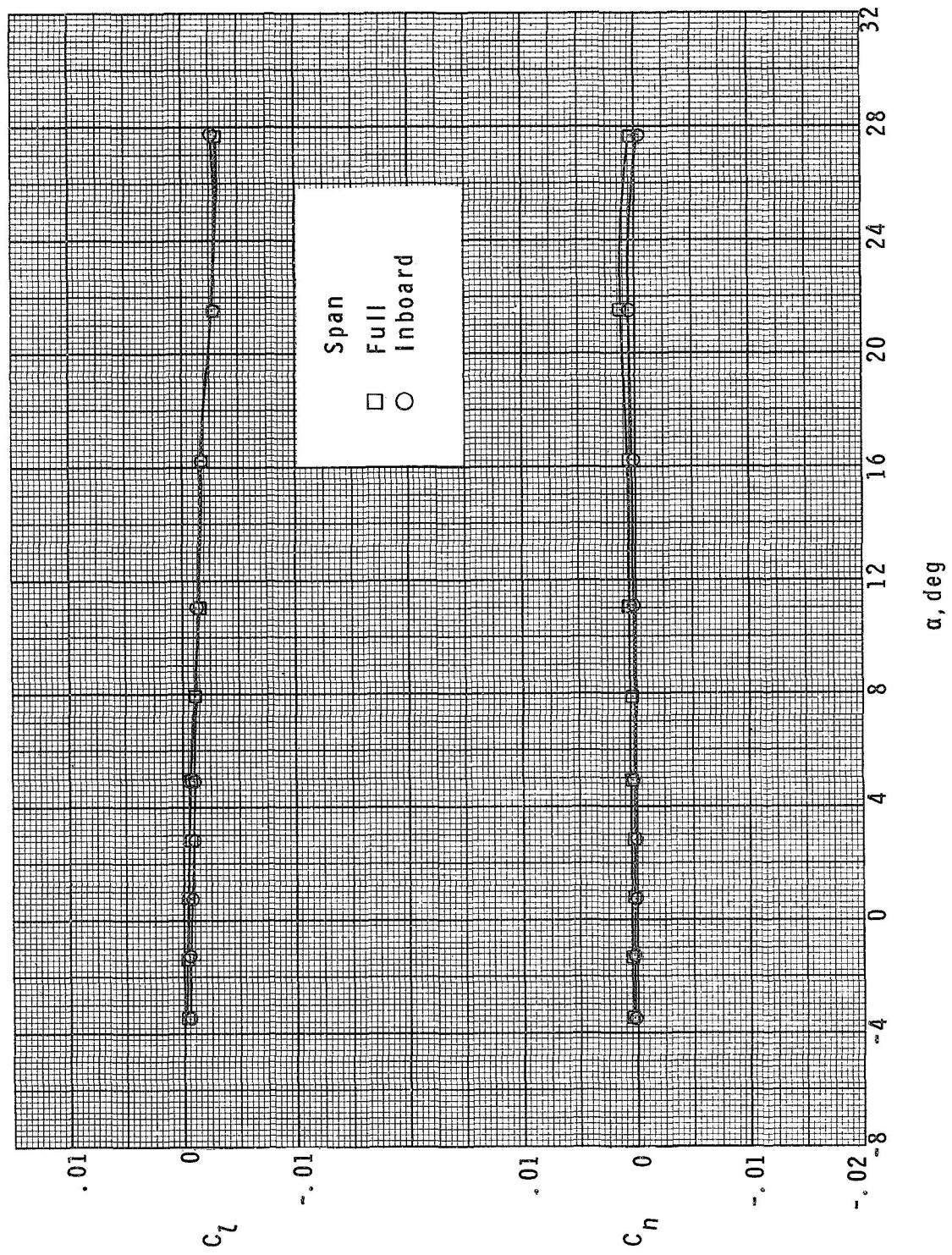
Figure 11.- Effect of span and spanwise location of lower surface spoiler with 75° swept wing.
 $h/c = 0.03$; $x/c = 0.75$.





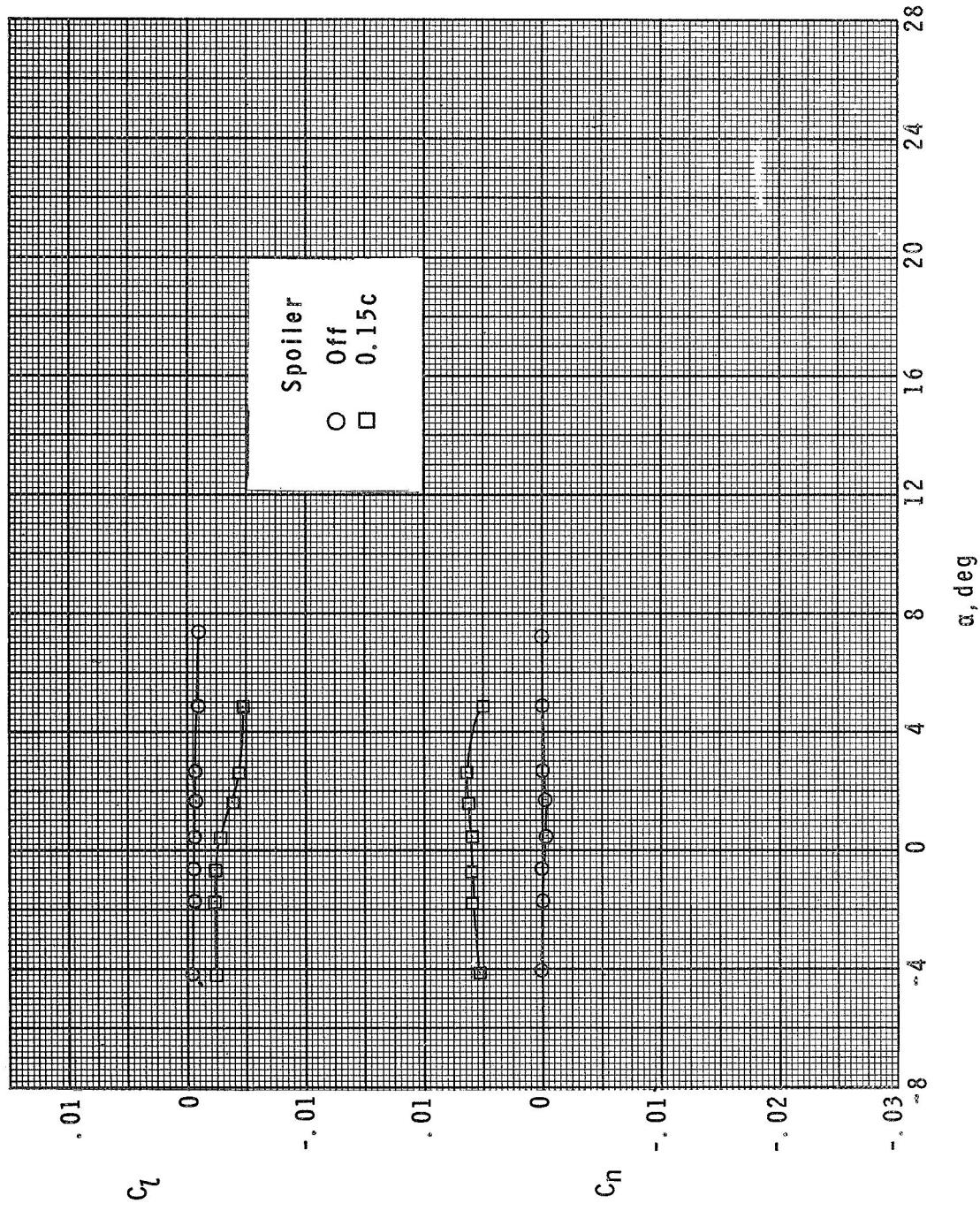
(c) $M = 3.96$.

Figure 11.- Continued.



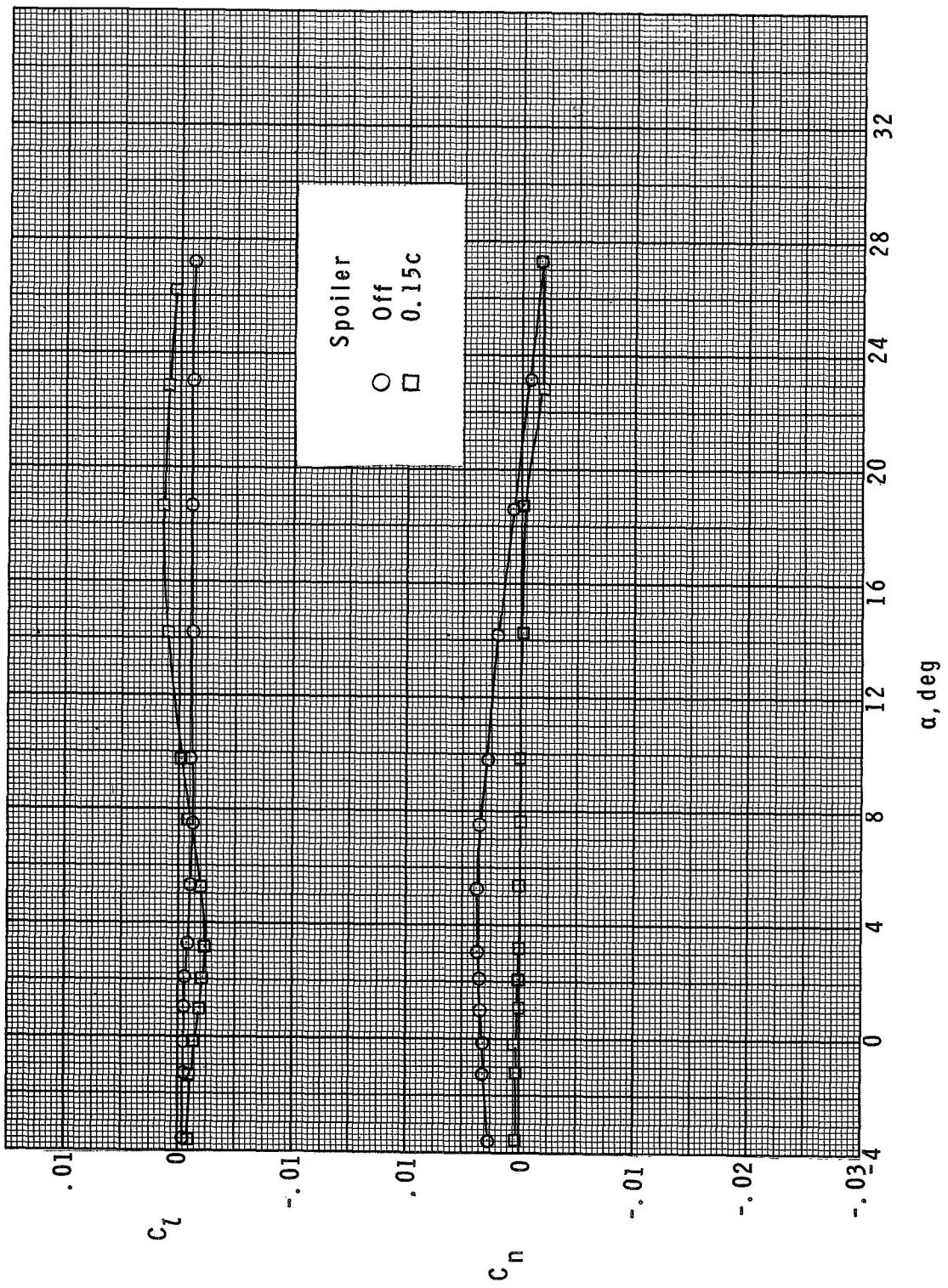
(d) $M = 4.63$.

Figure 11. Concluded.



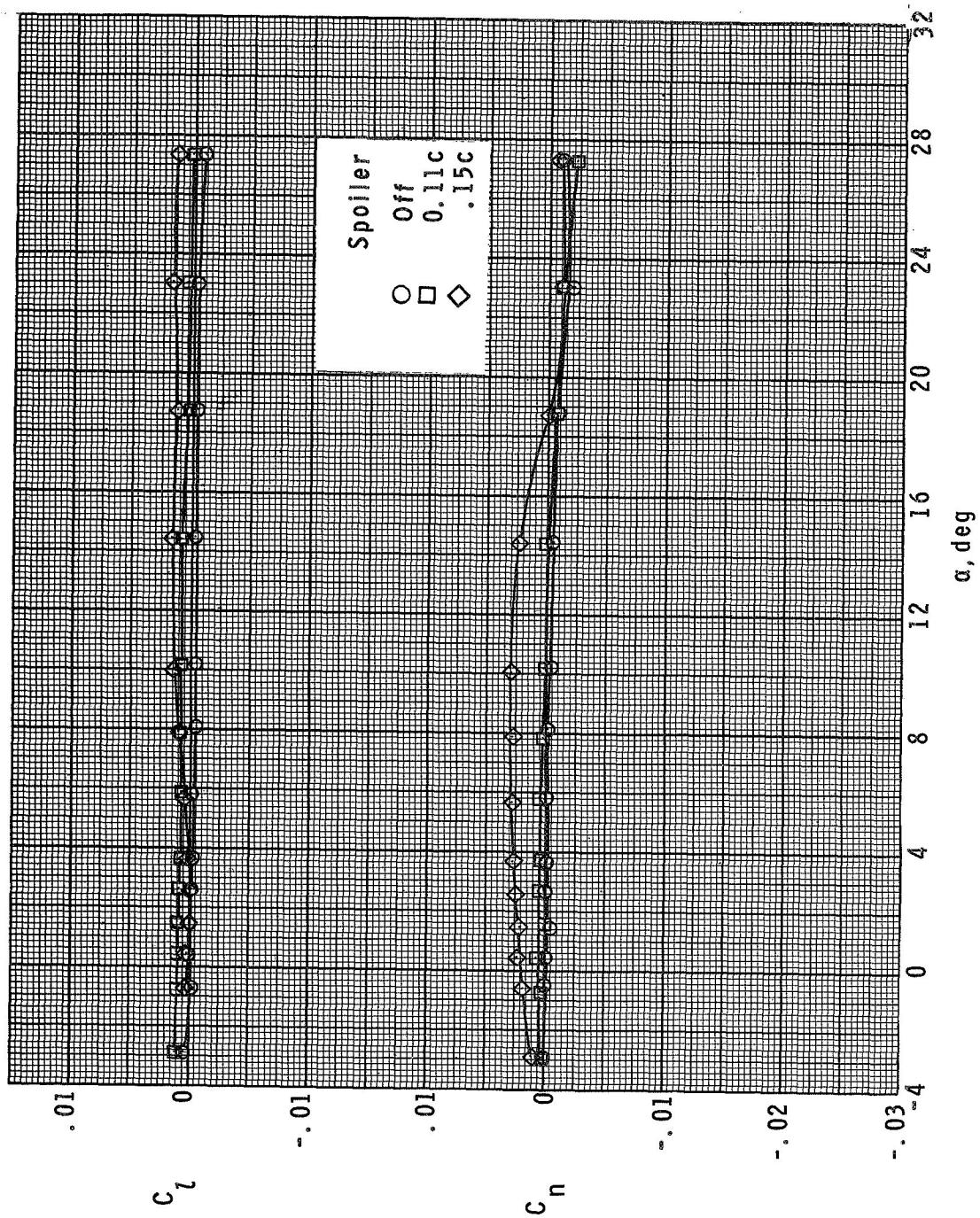
(a) $M = 1.50$.

Figure 12.- Effect of inboard spoiler with 75° swept wing.



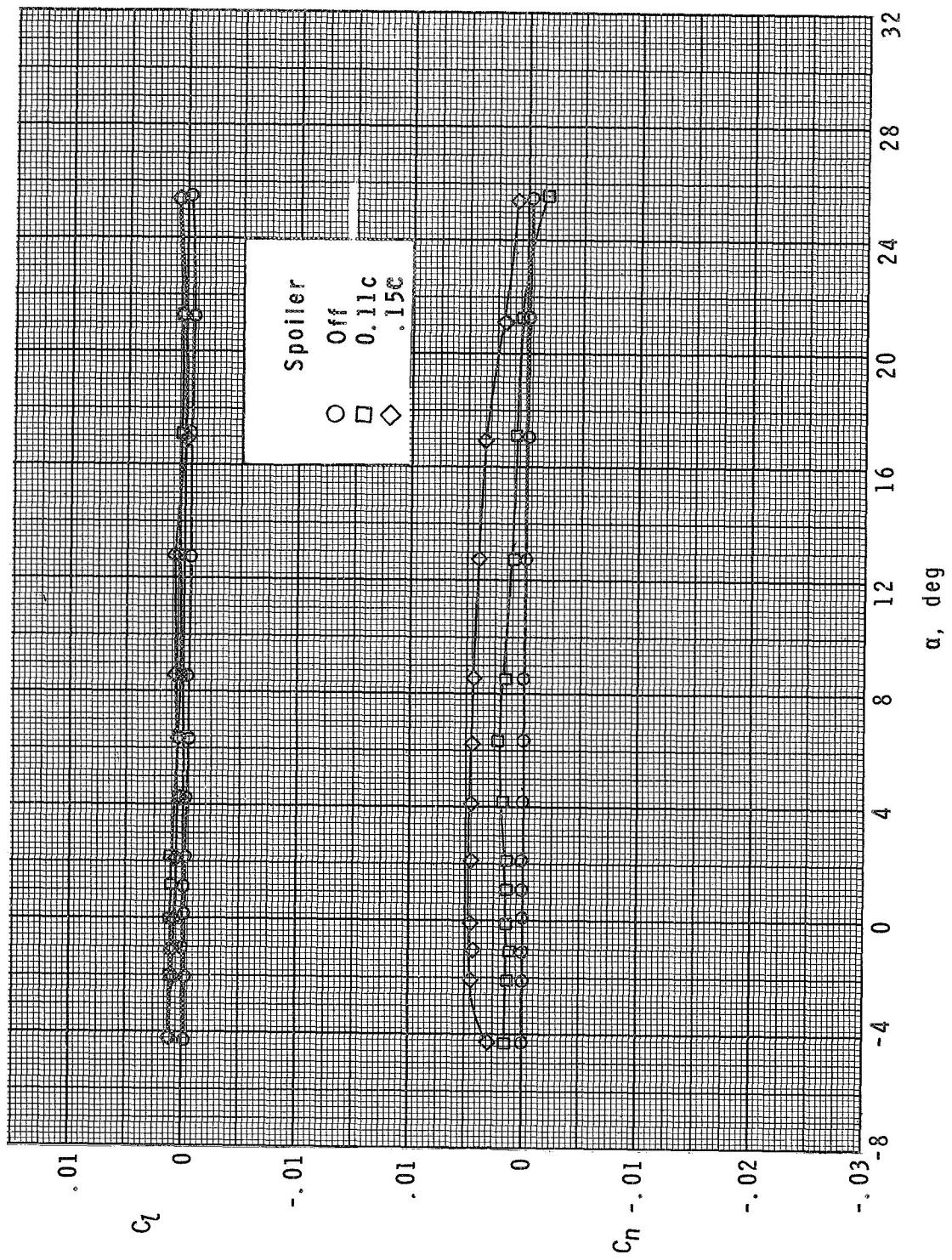
(b) $M = 1.90$.

Figure 12.-- Continued.



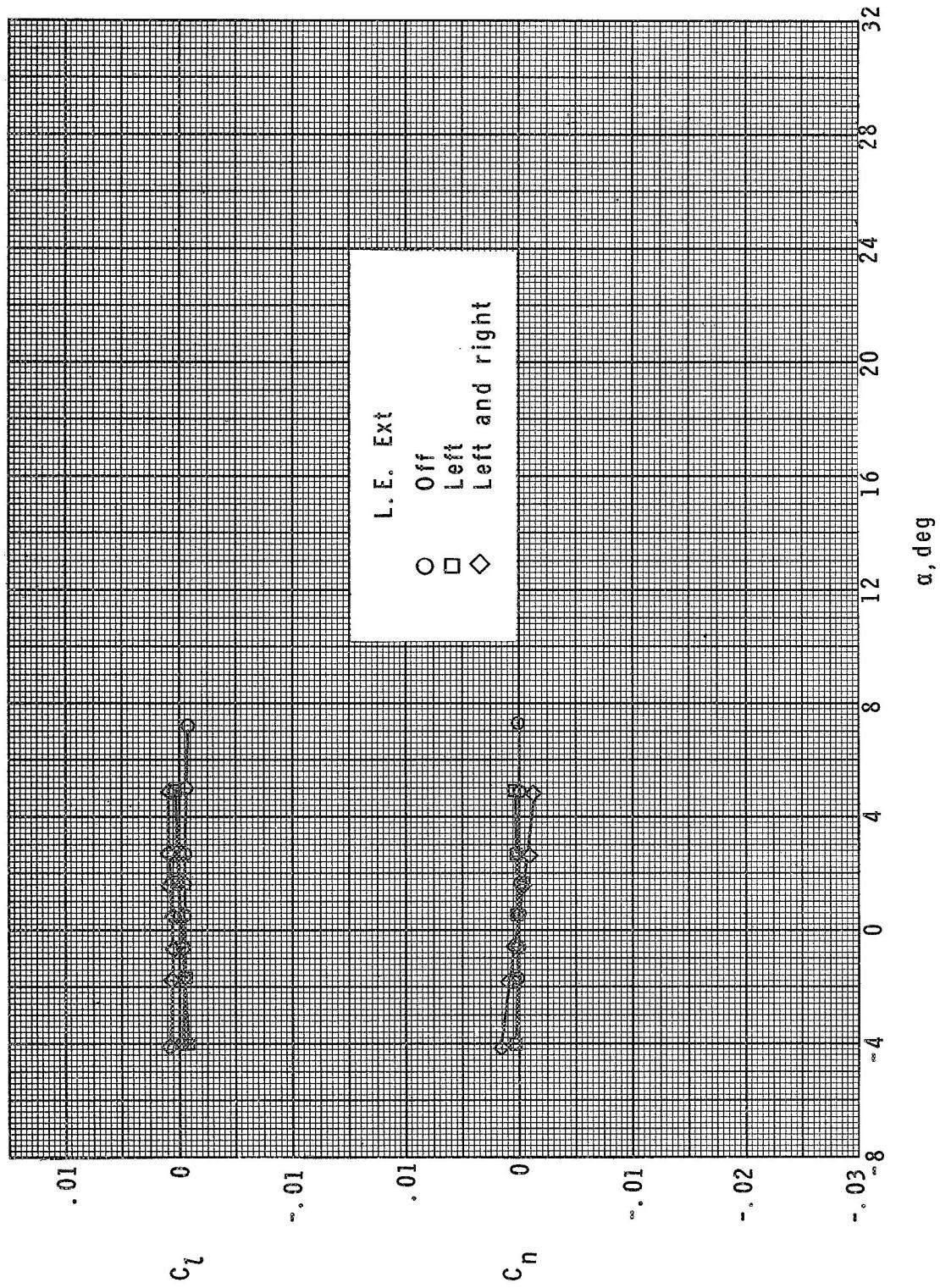
(c) $M = 2.36$.

Figure 12.~ Continued.



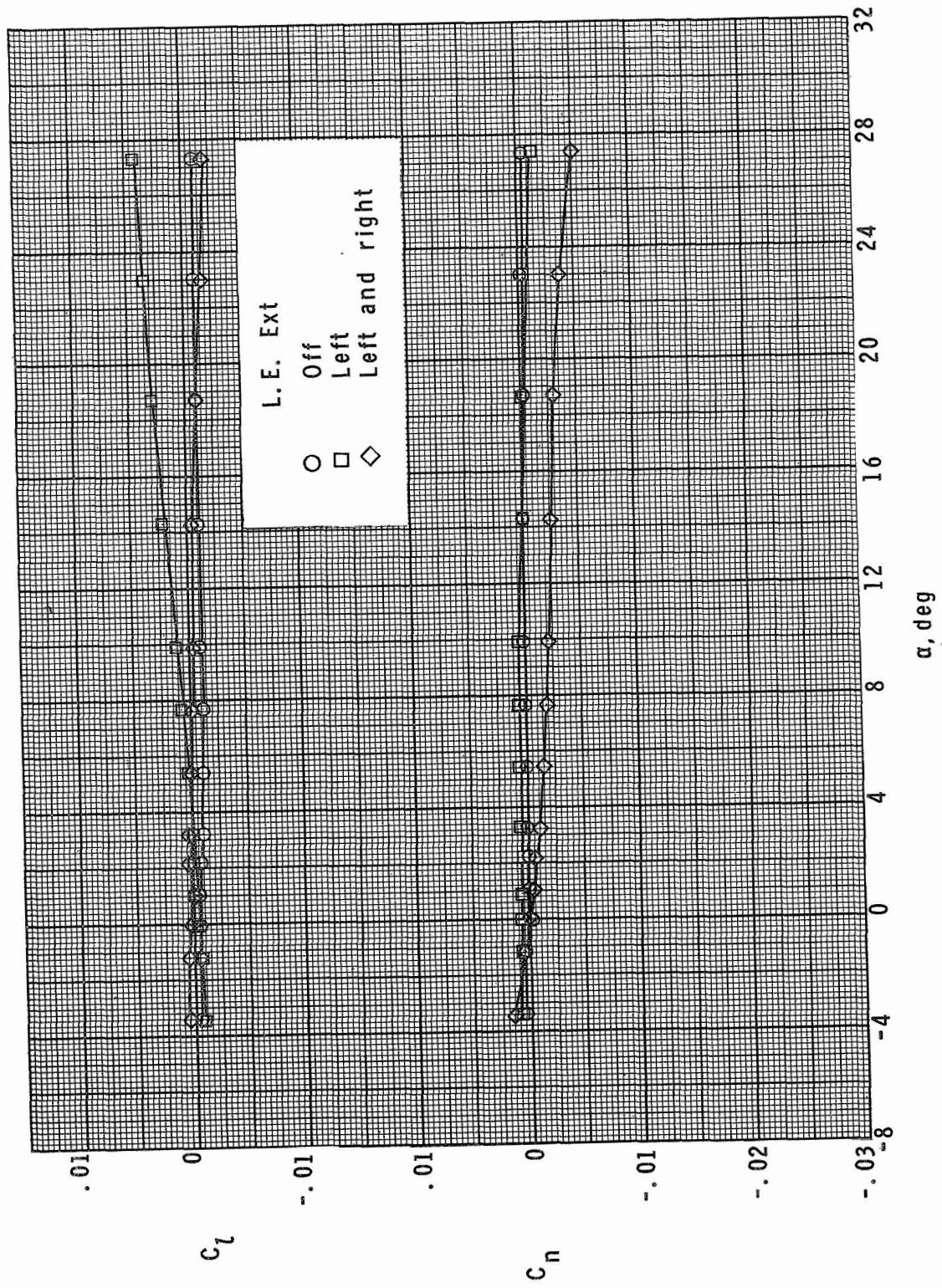
(d) $M = 2.86$.

Figure 12.- Concluded.



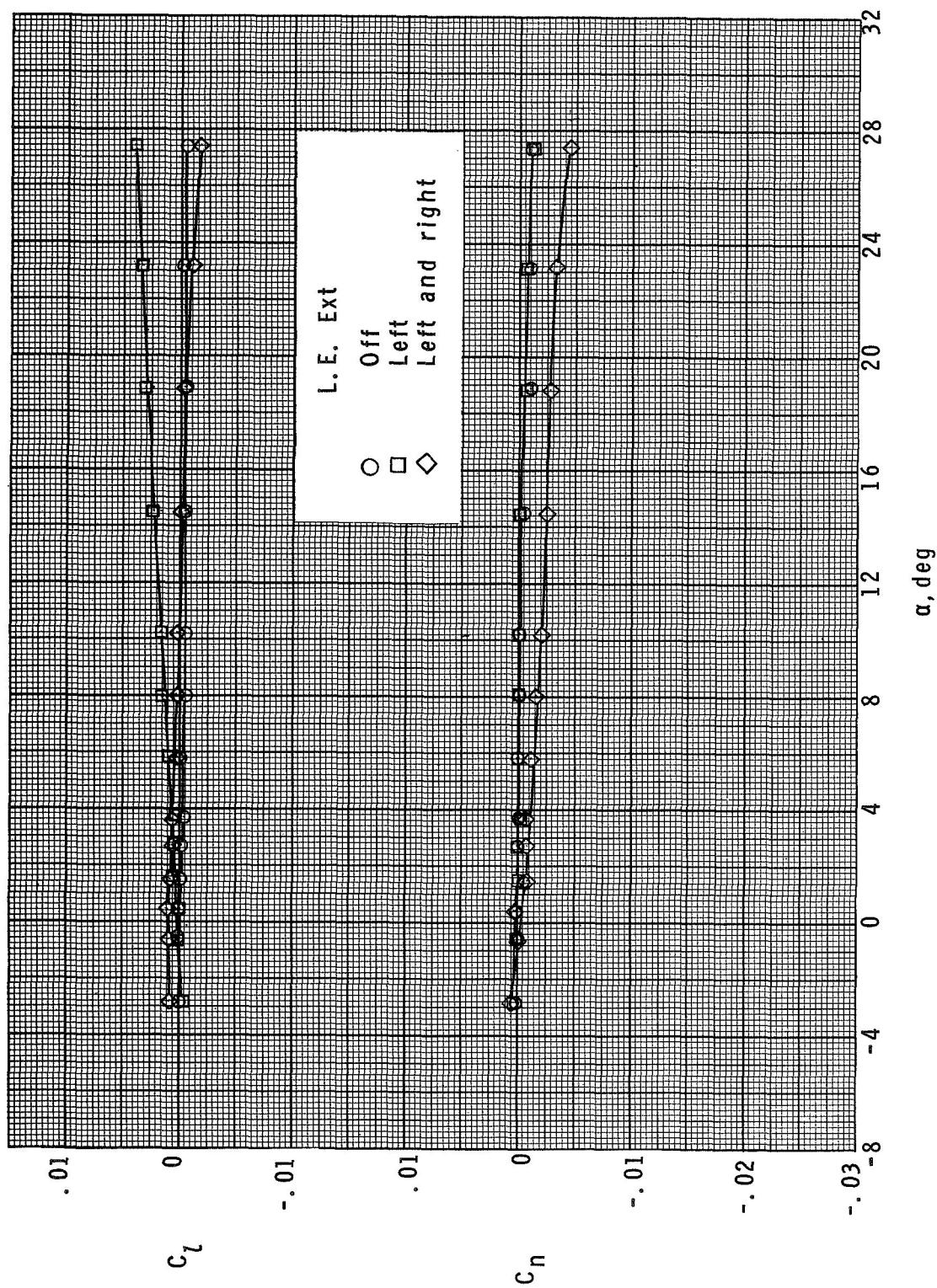
(a) $M = 1.50$.

Figure 13. Effect of leading-edge extensions.



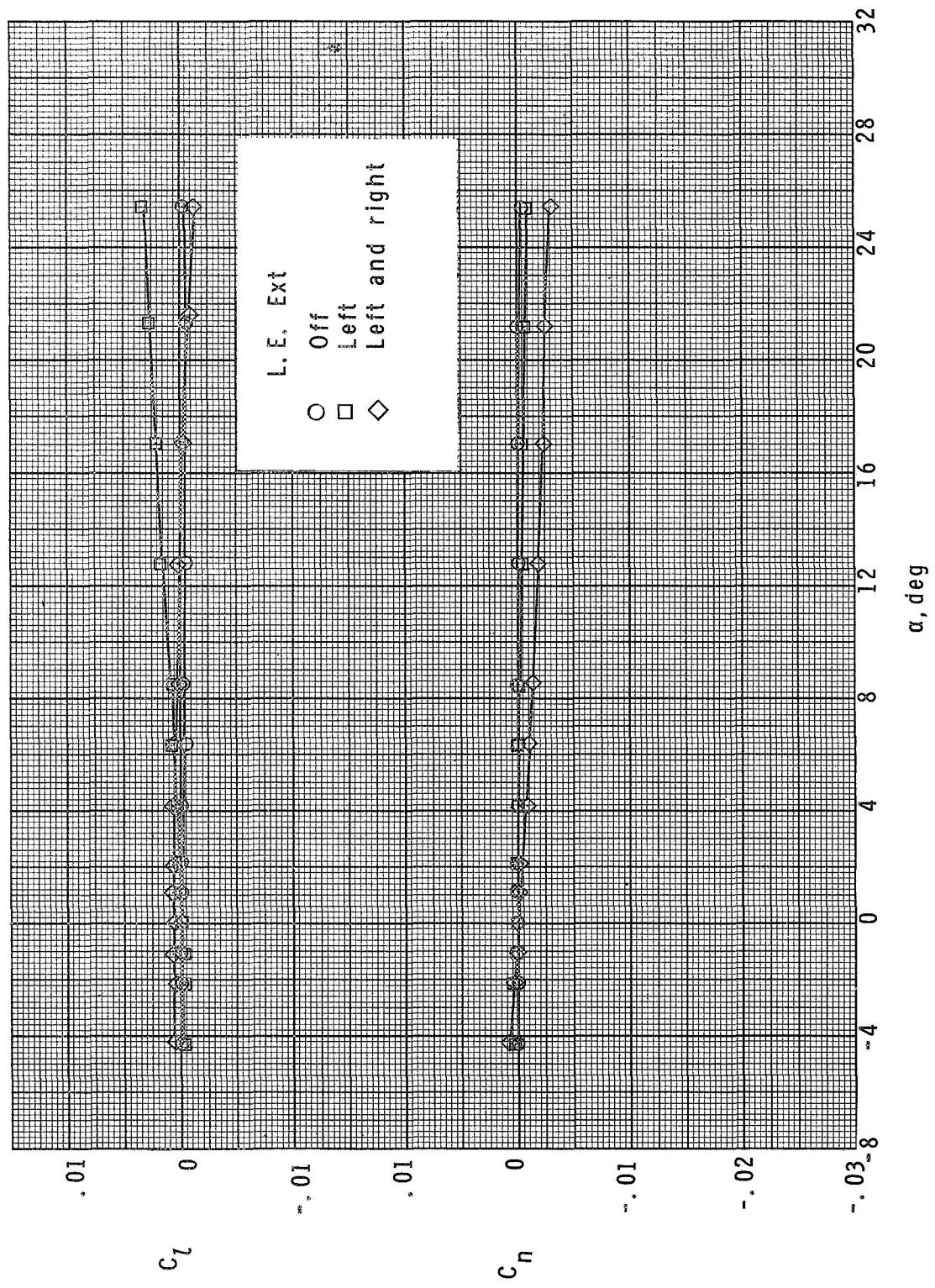
(b) $M = 1.90$.

Figure 13.- Continued.



(c) $M = 2.36$.

Figure 13(c).— Continued.



(d) $M = 2.86$.

Figure 13.- Concluded.

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